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Uranium In Situ Leach Mining in the United States

UNITED STATES DEPARTMENT OF THE INTERIOR

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Uranium In Situ Leach Mining in the United States

By William C. Larson

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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URANIUM IN SITU LEACH MINING IN THE UNITED STATES

by

William C. Larson [1]

ABSTRACT

This Bureau of Mines report discusses uranium in situ leach mining in the United States to acquaint the public with an overview of this emerging mining technology. This report is not intended to be a technical discussion of the subject matter, but rather should be used as a reference source for information on in situ leaching.

A list of in situ leaching publications is included as well as engineering data tables for almost all of the active pilot-scale and commercial uranium in situ leaching operators. These tables represent a first attempt at consolidating operational data in one source, on a regional basis.

Additional information is given that discusses the current Bureau of Mines uranium in situ leaching research program. Also included is a listing of various State and Federal permitting agencies, and a summary of the current uranium in situ leaching operators. Finally, a glossary of terms has been added, listing some of the more common terms used in uranium in situ leach mining.

INTRODUCTION

Purpose

The purpose of this Bureau of Mines report is to discuss the various in situ uranium leaching operations that recently were or are now in operation in the United States. In situ uranium leaching methods, when used as a single commercial mining method, represent a technological breakthrough of which many people are not familiar. A discussion of the current in situ uranium leaching methods should be helpful to those individuals who want to be updated on this mining method in a short period of time. The engineering data presented in appendix B give data that can be compared on a more regional basis or from operator to operator depending upon the situation.

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A list of in situ leaching publications, that covers both uranium and copper in situ leach mining, is also included. Although in situ copper leaching is not discussed, many of the articles listed describe both copper and uranium leaching in the same article. No attempt was made to single out these articles because many techniques that have been used in the copper leaching field may be applicable to uranium in situ leaching. A computer program has been developed at the Bureau's Twin Cities (Minn.) Mining Research Center to sort the listing by commodity and patent. That program, SEARCH, and publication listing is available in printout form from the Center.

Definition

During the past several years the terms in situ and in-place leach mining have been used with increased frequency throughout the mining industry. A review of relevant literature over the past 6 years will show that many companies are in the process of or were involved with research and development (field and laboratory) programs for in situ leach mining (see appendix A).

The term in situ leach mining can be defined as that selective mining technique whereby the ore mineral(s) that has not been transported from its geologic setting is preferentially leached (dissolved) from the surrounding host rock by the use of specific leach solutions and the mineral value(s) recovered. This definition can include the use of explosives or hydraulic fracturing techniques to fragment an ore body in preparation for in situ leaching. However, dump or heap leaching operations are not included because, in these systems, the material has been mechanically transported to prepared areas for leaching and thus removed from the original geologic setting. Consequently, in situ leach mining has a precise meaning in the context of this report. Uranium dump and heap leaching operations are not discussed.

The terms in situ leach mining or in situ leaching will be used throughout this report. The term in-place leaching will not be used. Other terms such as solution mining or borehole mining that have been used synonomously in the literature with in situ leaching will be avoided. In addition to the preceding definition, other terms that are relatively new when used in the context of in situ leaching are included in a glossary at the end of this report (appendix C).

Background

As previously indicated, the literature covering uranium in situ leach mining has expanded significantly in the last several years. First, there are numerous articles on the general aspects of in situ uranium leaching covering the state-of-the-art, the general principles involved, and discussions of some of the techniques that are used. Some of the references are articles that would be useful to someone who wants to have a general background on uranium in situ leaching (2-3, 8, 12-13, 17, 21, 23, 29, 32, 37-38).[2]

[2]Underlined numbers in parentheses refer to items in the bibliography preceding the appendixes.

In addition to the general articles, patents have clarified the more historical and technical aspects of in situ uranium leaching, not only on the process in general, but on specific techniques that have been developed (5, 9, 14-15, 18-20, 22, 25-26, 28, 34). By reviewing these patents, a better understanding of the evolutionary aspects of in situ uranium leaching can be obtained. Also, the more recent patents are becoming much more specific with regard to the methods used and the results reported.

Probably the most detailed public information available on in situ uranium leaching is through the various State and Federal agencies that require environmental reports (covering proposed activities, the mine site, the well field and processes, environmental impacts, etc.) to obtain a source material license. These permits and their respective issuing agencies will be discussed in more detail in a later section. These agencies have public document sections where anyone can review an environmental report for a specific operation. Some of the most recent references for source material permits describe in detail what the operator plans to do, the proposed time schedules, general process description, site geology, etc. (39, 46, 50-60).

Most of the requests for uranium in situ leach mining information concern costs, and often very little published cost information is available; however, there are a few articles available (4, 6, 16, 27, 33, 47).

Only one article has been found on the legal aspects of in situ mining (35). This article is particularly interesting with regard to some of the legal questions which might arise in the future.

The references cited are not meant to be an exhaustive review of the past literature on in situ uranium leach mining. For example, many of the technical aspects of the uranium leach chemistry, hydrology, fluid flow, etc., have not been included. However, the primary purpose of this publication is to update the interested or technical person in a fairly short period of time. For additional information appendix B should be reviewed.

For a more complete discussion, a brief summary of one of the first "modern" uranium in situ leach mines is discussed. Modern in this case refers to the injection-recovery well system, the design process such as an ion exchange extraction system, and the use of the ground water to control the leach solution flow.

The first modern uranium in situ leaching operation that has been discussed in detail was conducted by Utah Construction and Mining Co., now Utah International, Inc. (1, 11, 18). They used many of the same principles and techniques that are currently in use; for example, well completion techniques, continuous ion exchange systems, pattern drilling, etc.

In 1960, Utah Construction and Mining Co. started uranium production from an underground mine near Shirley Basin, Wyo. However, ground conditions were very poor and the mining costs were high enough that alternate mining methods had to be considered. At that time, in situ leach mining was a relatively new and untried technique.

During 1961-63, the company experimented with many different well spacings, drilling and well development techniques, and several types of leach solutions, including nitric and sulfuric acids. By 1963 the company had experimented with and tried five generations of well field designs and had drilled over 100 well field patterns in an attempt to optimize recoveries for its operation. The company was successful using these techniques and from 1963 to 1969 the in situ mining method was the only method of uranium production at the Shirley Basin site. The old in situ leaching site was replaced by Utah International's Shirley Basin open pit mine, and the original in situ leaching area was stripped during 1974.

The typical well field pattern consisted of three injection wells placed "upstream" from the production well with regard to the local ground water flow. Two side injection wells were placed on radii diverging at an angle of approximately 75° to the production well. The injection-production well spacing was approximately 25 feet with well depths ranging from 330 to 360 feet.

The injection-recovery well drilling techniques were standardized in the early 1960's. The wells were first pilot drilled and probed, and then they were reamed out to accept the proper diameter casing. The injection wells used 3-in-diam stainless steel casing, while the production wells used 8-in-diam steel casing with stainless steel on the bottom 40 feet of pipe within the ore zone. Cement baskets were placed above the ore zone and later the natural clay layers swelled around the casing to seal off the wells within the ore zone. The wells were developed by using 50-psi water jets and standardized flushing procedures.

The typical leach solution consisted of about 5 gpl H_2SO_4 using sodium chlorate as an oxidizer and a flocculant to enhance permeability. The usual practice was to inject the sulfuric acid leach solution in low concentrations ranging from 1.0 to 1.5 gpl H_2SO_4 until acid was detected in the production well. By using this practice, the theoretical solubility of the $CaSO_4$ in the ground water was not attained until the lime in the formation had been neutralized (1). The production flow rate averaged about 75 gpm and uranium concentrations in the pregnant leach solution ranged between 0.2 and 0.3 gpl. Usually three to five patterns (three recovery wells and one injection well per pattern) were in operation simultaneously.

Control of the leach solution was obtained by noting changes of the water level in nearby monitor wells. A rise in the water level indicated a need to increase production rates to contain the leach solution within the pattern.

In the early stages of in situ leach mining nitric acid was used as the leach solution. Generally, about 10 gpl nitric acid, 1 gpl sodium chlorate, and 10 ppm flocculant was the leaching agent (18) for producing uranium in concentrations up to 5 gpl. The company changed to using sulfuric acid primarily because of its lower cost and also because they could control the precipitation of calcium sulfate to maintain permeability. In situ leaching was discontinued in the late sixties when the decision was made to open pit the remaining reserves.

GENERAL GEOLOGY

The Energy Research and Development Administration, now part of the Department of Energy, estimated that over 96 pct of the U.S. uranium reserves occur in sandstone and conglomerate deposits (49). Therefore, it is not surprising that all of the current uranium in situ leaching operations (commercial and pilot-scale as defined by the operators permits) are being conducted in tertiary sandstone deposits.

To date, the uranium in situ leach mining activities have been concentrated in two States--Texas and Wyoming. However, several other States such as New Mexico, Colorado, South Dakota, Arizona, Utah, and Montana have received increased inquiries regarding the establishment of pilot-scale research and development operations. New Mexico and Colorado have had limited in situ leaching activities at the pilot-scale.

Uranium recovered by the in situ mining method occurs in the roll-type mineralized deposits. Roll-type, as used here, denotes the general case in which the uranium has precipitated out along the oxidation-reduction front in several configurations, such as the classic crescent shape, or more commonly, as tabular, dish-shaped, or irregular deposits. Such deposits, as shown in figure 1, describe the various types of ore body configurations. The deposits

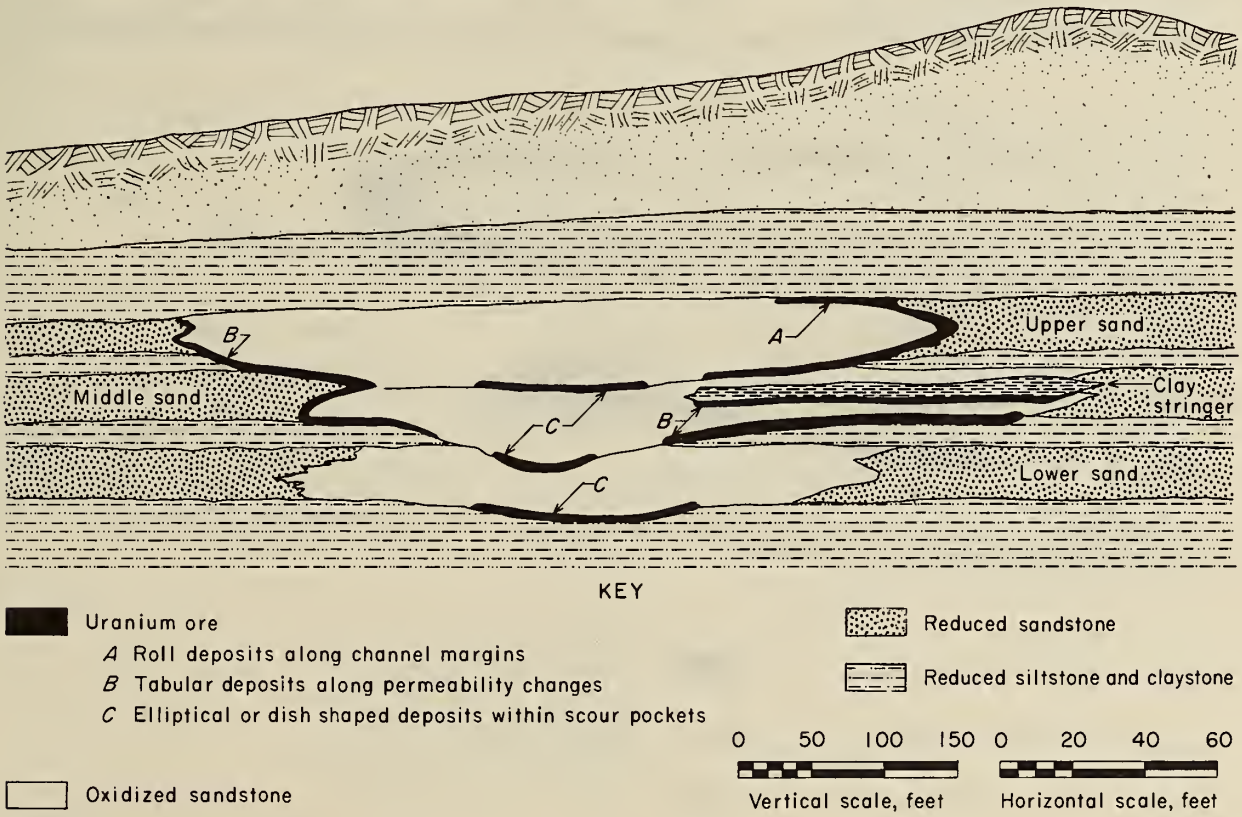

FIGURE 1. - A cross section showing configurations of the various types of uranium sandstone deposits (24).

that are amenable to in situ uranium leaching have been associated with relatively shallow ore bodies (less than 500 feet) beneath the water table which have been located within confined aquifers.

In general, the sandstone hosts for the uranium deposits are ancient channel sands that have been covered by more recent sediments. These sands are usually bounded above and below by impermeable mudstones or shales and interspersed with clay stringers (fig. 2). The degree of consolidation of these deposits ranges from unconsolidated to very tightly cemented, consolidated sandstones.

The uranium currently being mined by in situ methods was, in theory, originally formed when the uranium was leached from a source material and transported in a dissolved state. The probable moving mechanism for the transportation of the uranium is the ground water. As long as ground water conditions are such that the uranium is kept in the oxidized state (+6 valence) no precipitation would occur; however, uranium deposition would occur when ground water conditions change from an oxidizing to a reducing environment. Typically, in a roll-type deposit, uranium is distributed along various oxidation-reduction interfaces producing the irregular deposits.

The dominate uranium mineral associated with roll-type deposits is documented as uraninite; however, coffinite has also been identified as a minor

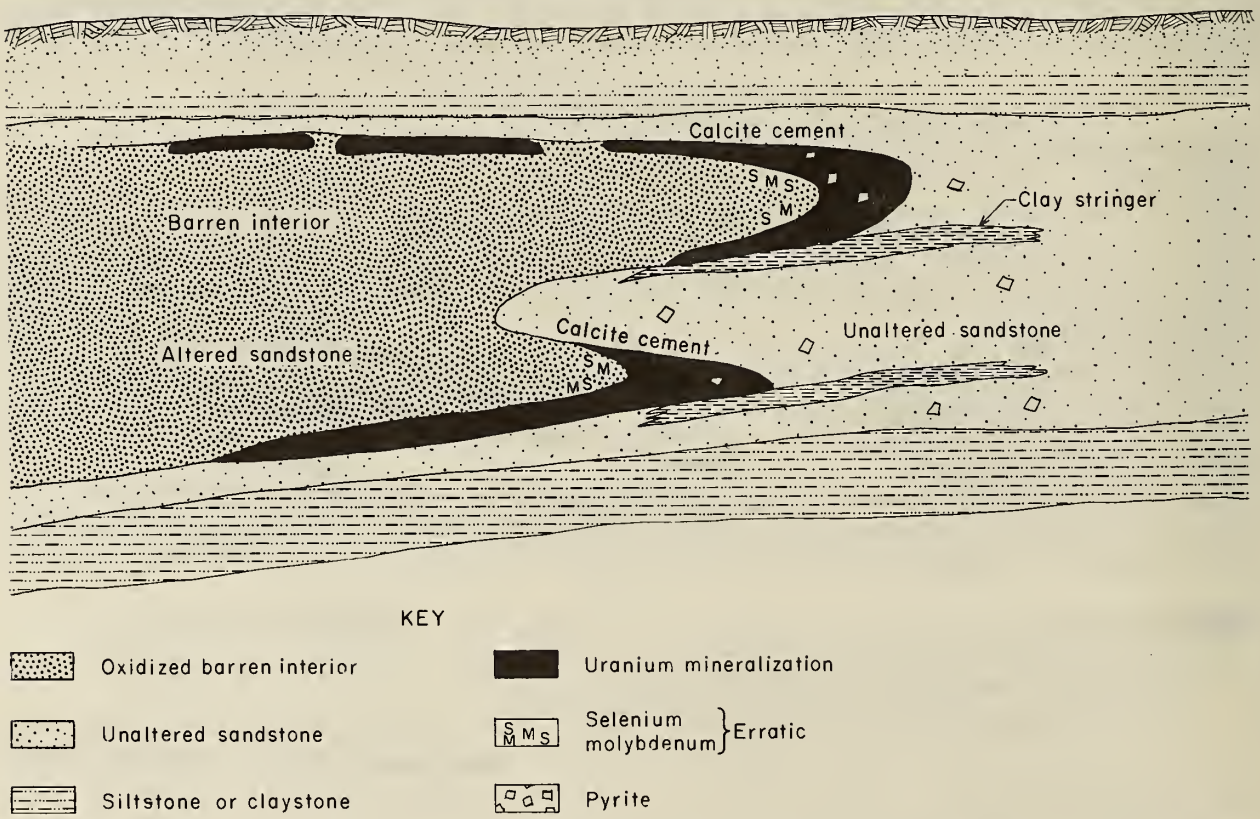

FIGURE 2. - A cross section showing the characteristics of an idealized uranium roll-front deposit (24).

uranium mineral in the ore deposits. Usually the uranium occurs as finely disseminated particles within the sandstone matrix or as a black coating on individual sand grains. The exact identification of these uranium minerals is often very difficult to determine even with sophisticated equipment.

In the past, the physical characteristics of the host sandstones for in situ leaching have shown a wide degree of variation, not only from deposit to deposit, but within the same ore bodies as well. For example, the sandstone grain size may range from very fine, to very coarse, to a conglomerate. The degrees of sorting of the sands are usually fair to poor, with individual grain roundness ranging from angular to subangular. Permeabilities of the sandstones range from essentially 0 to 5,000 md. Also the direction of permeabilities within the sandstone appears to be highly anisotropic, with horizontal to vertical permeability ratios ranging in the order of 10:1.

PROCESS DESCRIPTION

In general, in situ uranium leach mining consists of injecting a suitable leach solution (lixiviant) into the ore zone(s) below the water table; oxidizing, complexing, and mobilizing the uranium; recovering the pregnant solution through production (recovery) wells; and finally pumping the uranium-bearing solution to the surface for further processing. Various types of injection-recovery well configurations or patterns have been used in the past. The most common patterns in plan view are shown in figure 3. More specifically, carefully constructed injection wells are used to inject a suitable leach solution,

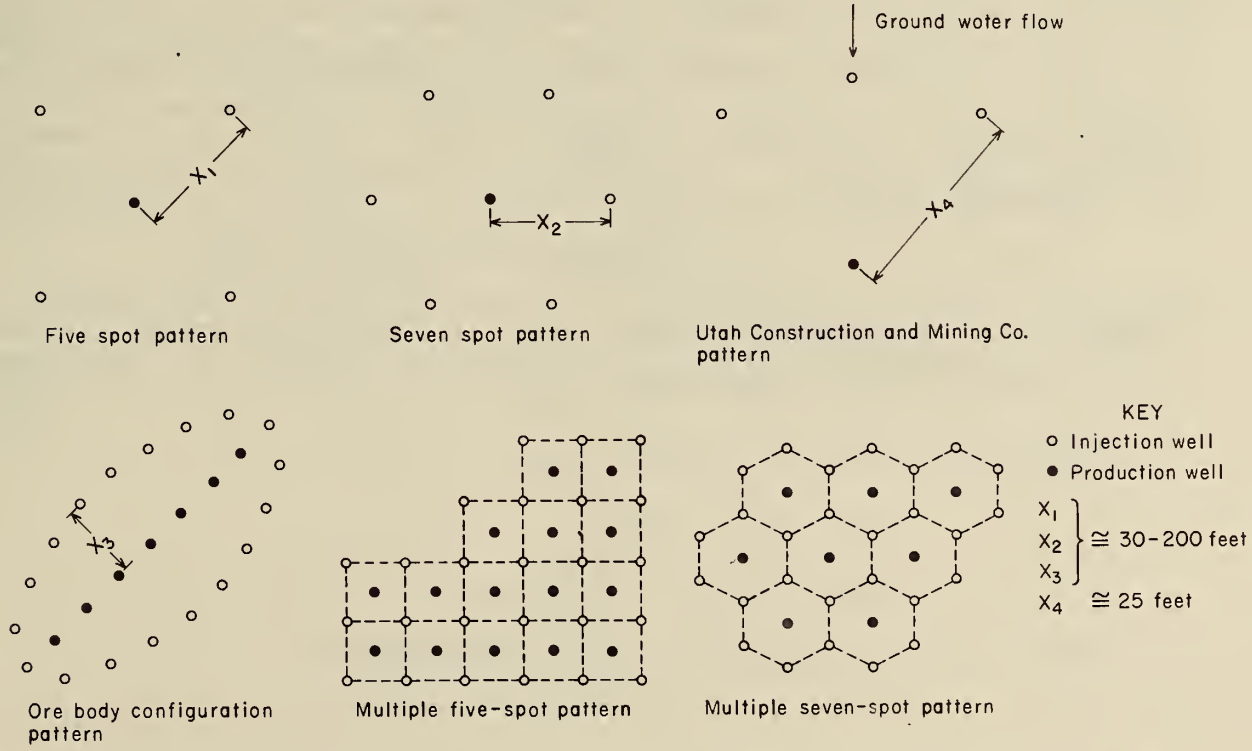

FIGURE 3. - Diagrams showing plan views of the common injection-recovery well patterns used in uranium in situ leach mining.

usually dilute concentrations of ammonium carbonate-bicarbonate or sulfuric acid, and an appropriate oxidizing agent, usually hydrogen peroxide or oxygen, into the uranium ore zone(s). The leach solution migrates through the permaable sandstone and comes in contact with the uranium minerals that are predominately uranium oxides and silicates, and the oxidizer oxidizes these minerals from the +4- to +6-valence state dissolving the mineral values. The uranium is then mobilized as a soluble uranium carbonate complex if a carbonate leach solution is used, or as a uranium sulfate complex if a sulfuric acid leach solution is used.

The following series of formulas describe the uranium minerals, and the alkaline-acid leach conditions previously described.

Predominant uranium minerals (30):

Uraninite = $(U^{+4}_{1-x}, U_x^{+6})O_{2+x}$ ideally UO_2.

Coffinite = $U(SiO_4)_{1-x}(OH)_{4x}$.

Ammonium carbonate leach reactions:

Oxidation = $UO_2 + H_2O_2 \rightleftarrows UO_3 + H_2O$.

Leaching = $UO_3 + H_2O + 3(NH_4)_2CO_3 \rightleftarrows (NH_4)_4UO_2(CO_3)_3 + 2NH_4OH$,

$UO_3 + 2NH_4HCO_3 \rightleftarrows (NH_4)_2UO_2(CO_3)_2 + H_2O$,

and $UO_3 + 2NH_4HCO_3 + (NH_4)_2CO_3 \rightleftarrows (NH_4)_4UO_2(CO_3)_3 + H_2O$.

Sodium carbonate leach reactions (29):

Oxidation = $2UO_2 + O_2 \rightleftarrows 2UO_3$.

Leaching = $UO_3 + Na_2CO_3 + 2NaHCO_3 \rightleftarrows Na_4UO_2(CO_3)_3 + H_2O$.

Sulfuric acid leach reactions (30):

Oxidation = $UO_2 + 2Fe^{+++} \rightleftarrows UO_2^{++} + 2Fe^{++}$.

Leaching = $UO_3 + 2H^+ \rightarrow UO_2^{++} + H_2O$,

$UO_2^{++} + SO_4^{--} \rightarrow UO_2SO_4$,

$UO_2SO_4 + SO_4^{--} \rightarrow [UO_2(SO_4)_2]^{--}$,

and $[UO_2(SO_4)_2]^{--} + SO_4^{--} \rightarrow [UO_2(SO_4)_3]^{-4}$.

Once the uranium minerals are complexed and mobilized, they follow the solution flow through the ore zone towards a production well where submergible pumps transfer the uranium-bearing solution to the surface for processing. The uranium in this pregnant leach liquor is recovered by ion exchange techniques. The residual uranium barren solution from the ion exchange operation is regenerated with suitable leaching chemicals and recirculated to the well field. Ion exchange is a cyclic operation that consists of two steps; the loading or absorption step and the elution step. During the loading step, the pregnant leach solution contacts the ion exchange resin, and the uranium is selectively absorbed. When a suitable uranium loading has been achieved, the resin is cycled to the elution step. During elution, the resin is contacted with a chemical solution that strips the uranium from the resin; the resulting product solution is termed the eluate, and the eluted resin is cycled back to the loading operation. Both concentration and purification take place during the ion exchange operation. Several types of ion exchange equipment arrangements have been used by in situ leaching operations. These include fixed-bed columns which use batch-type operational procedures, and multiple compartment column systems that operate with semicontinuous countercurrent flow of both the solutions and the resin (29-30, 48).

The uranium is recovered from the eluate by precipitation, and the recovery procedure is dependent upon the type of solution used for the elution step. For example, if the uranium is eluted with an acidic salt solution, the precipitation can be made by direct neutralization with ammonia. The yellow-colored precipitate is primarily ammonium diuranate which is normally termed yellow cake. If an alkaline carbonate eluting solution is used, the precipitation technique must be modified. Before the uranium can be precipitated with ammonia, the carbonate complex must be destroyed or the precipitation will be incomplete. This destruction can be accomplished by adding an acid such as HCl. Once the carbonate has been eliminated, the uranium can be precipitated by ammonia neutralization. The yellow cake precipitate is separated from the residual solution by thickening and filtration. The filter cake is then dried and packaged for shipment. A block flow diagram of one commercial-scale in situ solution process plant is shown in figure 4.

Additional information on specific site processes are shown in the environmental reports that have been prepared by the various operators to meet requirements for obtaining a source material license (39-46, 53, 55, 57, 59-60).

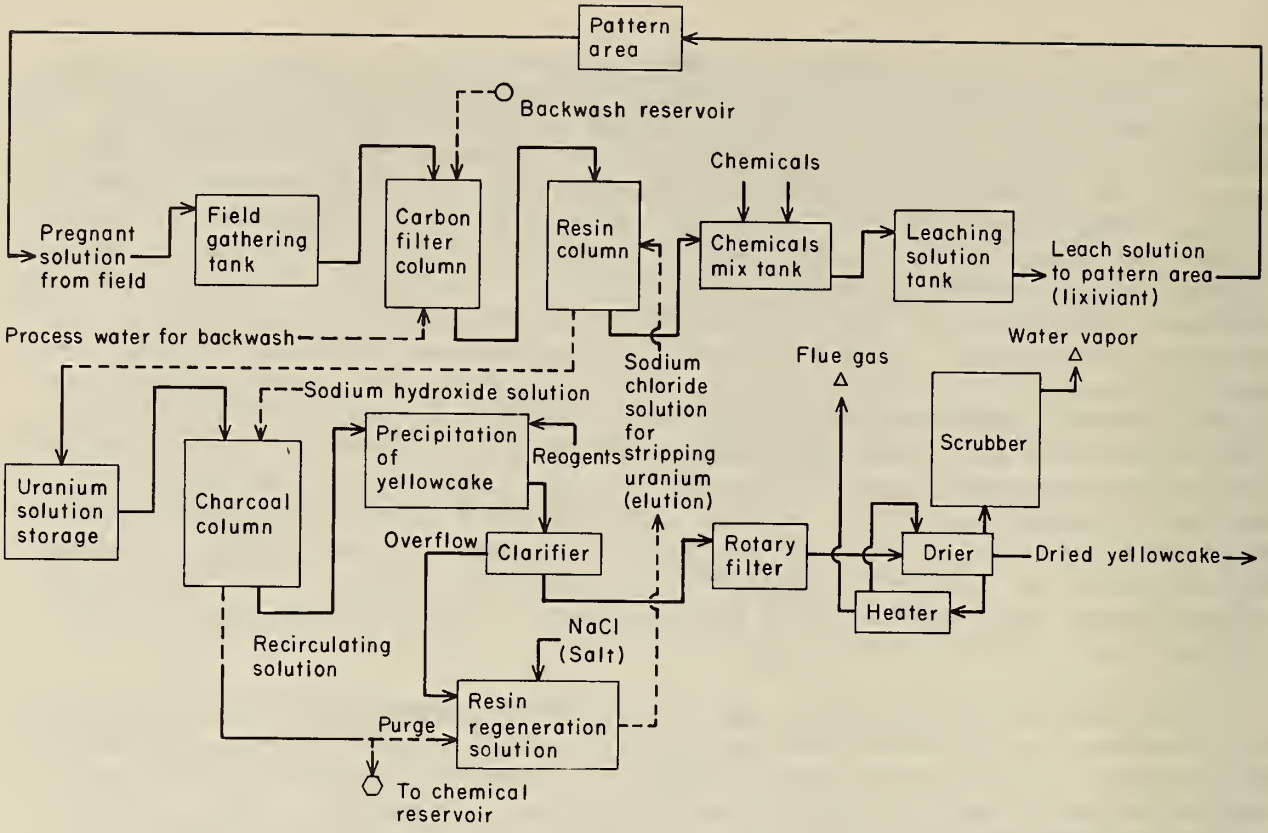

FIGURE 4. - Block flow diagram for a uranium in situ leach mining operation (44).

TIME SCHEDULE FOR A PILOT-SCALE OPERATION

The time schedule for the commissioning of a pilot-scale uranium in situ leaching operation varies with each operator. There are many variables that influence the size and rate at which an operation comes on-stream, such as project funds, personnel expertise, geographic location, amount of research and development (R&D) work, geology, hydrology, time schedule, licensing procedures, etc. Keeping these variables in mind, an example time schedule for a research and development in situ project is shown in figure 5. This schedule should be regarded as an approximation and it is dependent upon what the operator wants to accomplish and the size of the proposed operation. A 2- to 3-year testing and evaluation program is common; however, operators have spent from 1 to 6 years conducting field feasibility tests before initiating plans for an expanded pilot-scale or full-scale operation.

In the past, operators have continued their R&D tests at more than one site to evaluate different parameters such as changes in leach solution chemistry, different well completion techniques, or changes due to local variations in the geology of the ore body. Also, operators have shortened their surface plant construction time by incorporating portable ion exchange units mounted on flatbed trailers. Geographic considerations are also very important. For example, pilot-scale operations in Texas can function year-round,

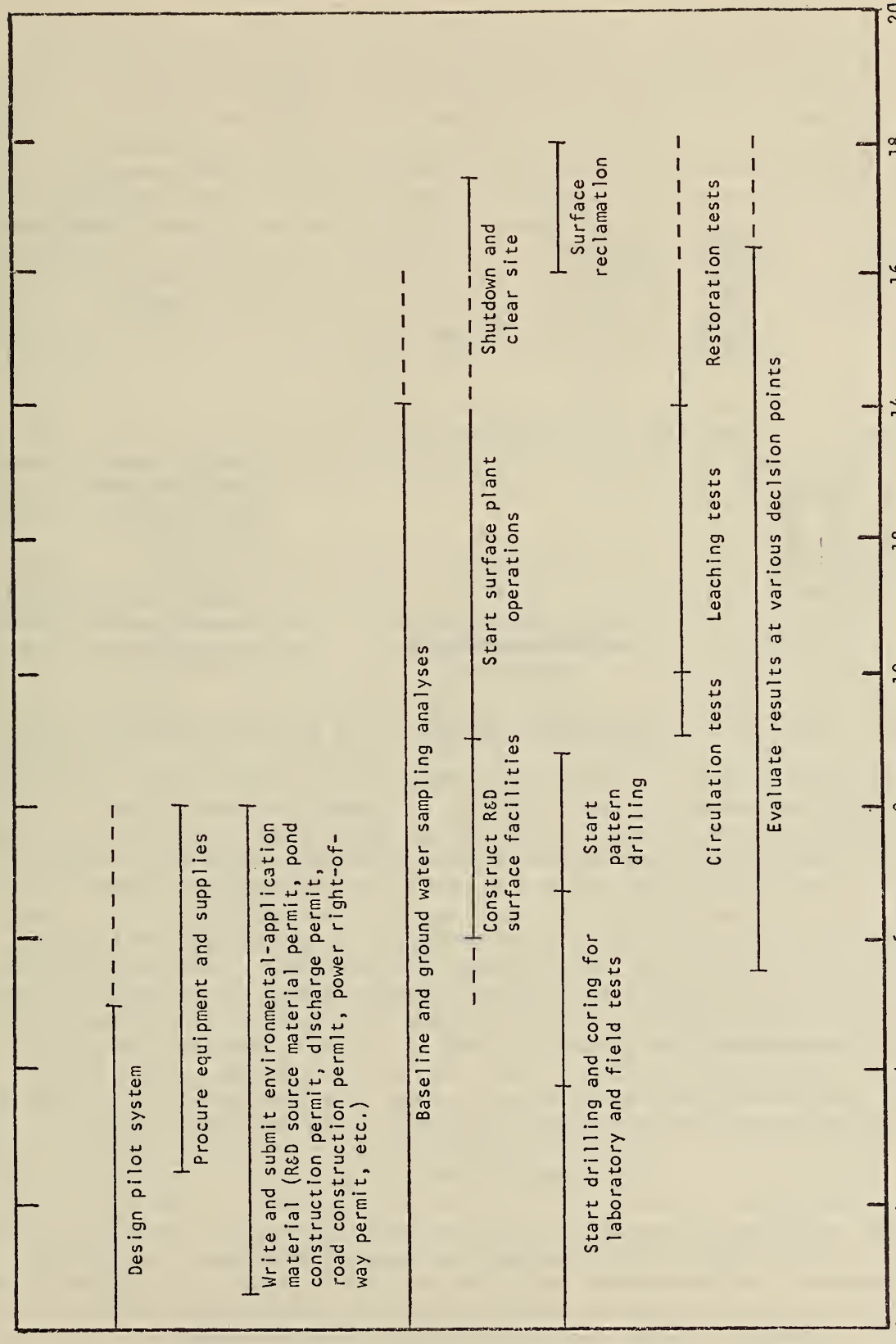

FIGURE 5. - An example time schedule for a pilot-scale uranium in situ leaching operation.

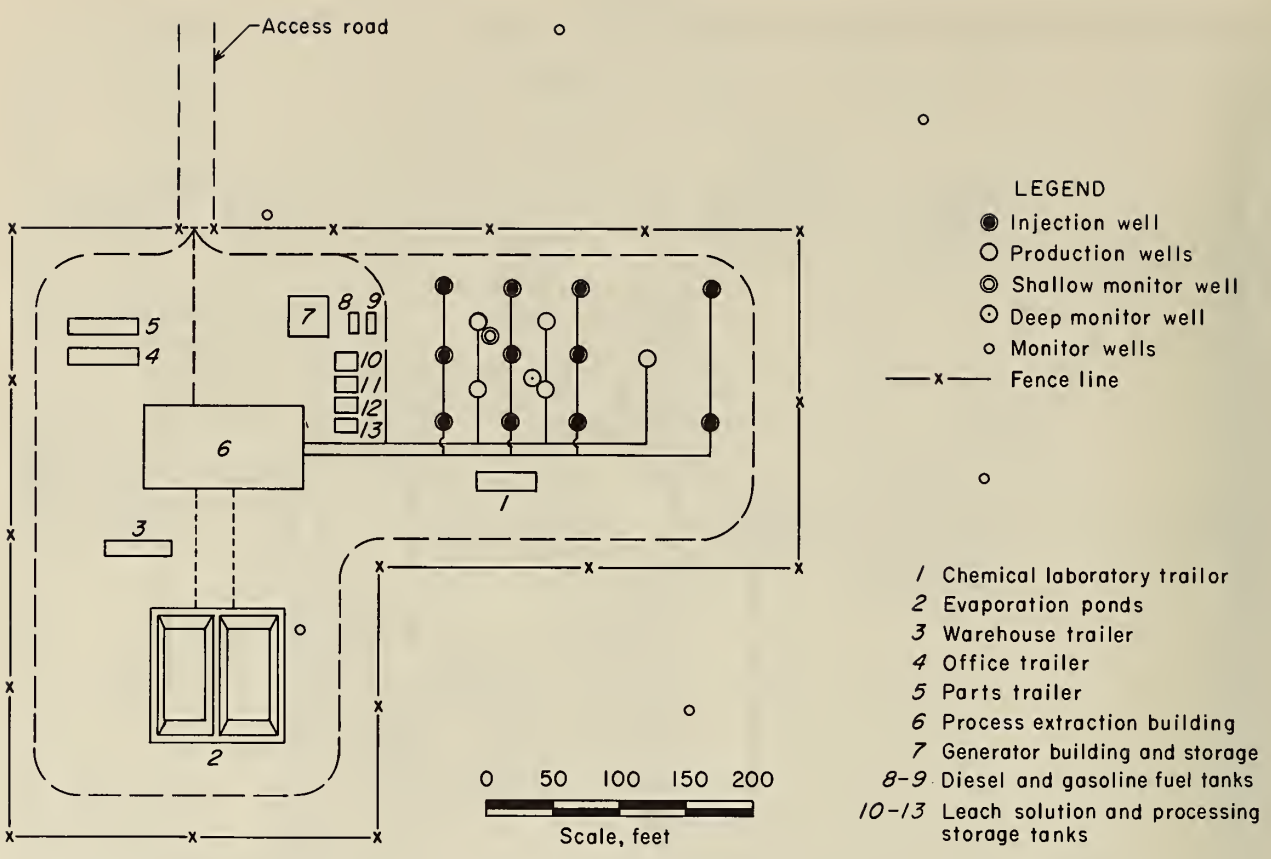

FIGURE 6. - Plan view of a hypothetical pilot-scale uranium in situ leach mining operation.

while in Wyoming special considerations must be given to drilling, freezing of surface pipes and processing solutions, etc. Finally, operators must allow sufficient time for the filing and processing of permits. Currently, the time schedule for obtaining an R&D source material license from the U.S. Nuclear Regulatory Commission is about 6 to 7 months, while a commercial source material license takes approximately 12 to 18 months. In addition to the example time schedule, the plan view of a hypothetical pilot-scale uranium leaching operation is shown in figure 6 which would be considered a fairly ambitious "first attempt." The operation includes a semipermanent processing plant, all of the necessary test facilities, and enough well patterns (present and future) to evaluate variables such as the type of leach solutions and oxidizers, well completion techniques, well spacing, fluid flow conditions, etc. To evaluate the feasibility of in situ leaching at a particular site, a plant of this size would be capable of handling R&D efforts for several years.

WELL CONSTRUCTION METHODS

Proper well construction and completion methods are one of the most important aspects of in situ uranium leaching in terms of bringing a well field into production. If a completed well does not function as it was intended and another well must be drilled, essentially the cost would be doubled. An inoperative recovery well may mean lower overall uranium recoveries.

In the past, injection wells, production wells, and monitor wells have not been constructed exactly alike. Companies have developed their own methods and techniques which depend upon previous experience, geology and hydrology of the formation, and to some extent budgeting requirements. However, the purpose for constructing and completing these wells is the same. The wells should function as they were intended and be constructed to isolate the various aquifers above and below the ore zone so that intermingling of the natural ground water from more than one zone does not occur. Conversely, during actual leaching operations the wells should be constructed so that the leach solution is confined to the aquifer within the ore zone and does not travel up around or below the casing to other aquifers. These considerations have both environmental and economic implications and are of equal importance to both the regulator and the operator.

As previously indicated, there are several methods used by industry to construct and complete in situ uranium leaching wells; some of the more common techniques are in the following discussion. It should be remembered that variations to these techniques are common and combinations of these construction methods have been used.

One of the more common methods (procedure A) for constructing and completing in situ uranium leaching wells is to drill a hole to a depth that is just below the ore zone or to the base of the ore-producing sandstone. Various drilling techniques have been used; however, rotary drilling is the most common. Also, many operators have experimented with drilling fluids, foam and air drilling, and reverse circulation techniques. Depending on the field or geologic conditions most of the techniques have been successful for a particular deposit, but field experimentation is very important. In addition to the different drilling techniques, various types of drilling fluids are needed. Water, bentonite, and guar gum base polymers have been tried with varying degrees of success. Usually onsite experimentation can determine the best combination of drilling techniques to use depending on the purpose and physical and hydrologic characteristics of the ore-bearing zone.

After the hole has been drilled to total depth, it is usually flushed with formation water to remove any drill cuttings and sidewall "cake" that has formed. Mechanical brushes, sidewall scrapers, and chemicals have been used to clean the hole in the ore-bearing zone, again with varying degrees of success, depending primarily on the geological and hydrological conditions.

After the hole has been flushed, a string of polyvinyl chloride (PVC) pipe is lowered down the hole. Usually a PVC screen or slotted casing of the same diameter is attached to the bottom of the casing. The PVC pipe is lowered down the hole until the screen is opposite the ore zone. A subjoint is usually attached above the screen that contains a plaster of paris plug and a wooden cap. The cap prevents foreign material, especially cement, from accumulating on the screen during the cementing operation. Weep holes are drilled above the plug through the casing to allow the cement to flow through the annulus between the outside of the casing and the drill hole. Just below the weep holes, a cement or shale basket is placed around the casing to protect the screen from clogging by preventing the downward flow of cement. In

addition, one or more centralizers are usually spaced at 20-foot intervals up the casing to insure a uniform cement flow and thickness around the casing. Finally, cement (usually type II construction or class A or B portland cement) is pumped through the casing displacing the water and drilling mud in the annulus until the cement is circulated to the surface. Various additives have been tried to insure a better cementing job such as the use of bentonite, mica and cellophane flakes, or even fiberglass. Usually water is pumped down through the casing and displaces the cement slurry except for about 10 to 30 feet inside the casing above the plug. From 10 to 100 pct of additional cement is required to complete the cementing depending upon the site conditions.

Before the cement reaches maximum strength, which could be from 5 to 10 hours, the cement column and wooden plug are drilled out. The result of this method is that the casing is cemented through all of the overlying formations and aquifers preventing vertical communication between the ore zone and the other aquifers. After the well has been completed, a variety of development procedures have been used such as flushing, jetting, airlifting or surging, including gravel packing and the use of chemicals. Figure 7 is a cross section of a well constructed in the manner described.

Another well construction method (procedure B) is to drill the initial hole several feet above the ore zone. The drill hole can be of the final diameter to accept the appropriate size casing or in some cases a smaller pilot size hole is first drilled and then the hole is reamed out to the proper diameter. The next step is to lower the casing down the hole to within a foot of the bottom. The casing is usually equipped with several centralizers spaced from 10 to 20 feet apart at the bottom of the casing. Usually, if the hole deviation is kept to a minimum (<3 pct), the casing will slide down the drill hole; however, in some cases it is necessary to wash the casing into the hole by circulating drilling mud or water down the casing and up the annulus between the casing and the sidewall of the drill hole.

Cementing of the casing is accomplished by pumping cement down the inside of the casing under pressure. The cement flows through the opening at the bottom of the casing and up along the sidewall to the surface. After the cement hardens, the cement plug left in the casing is drilled out and the hole lengthened by drilling into the mineralized sandstone. Finally, the mineralized zone is drilled and underreamed from 3 to 6 inches. Depending upon the competency of the formation, a screen may not be needed in an injection well. For recovery wells, which use submersible pumps, a smaller diameter PVC screen or slotted pipe can be placed inside the casing and opposite or slightly above the ore zone. In most cases a packer is used to seal off the junction between the casing and screen to prevent upward movement of sand during operation. In addition, an adaptor can be placed on the screen to allow it to be pulled for changing or periodic cleanup. A cross section of this well construction method is shown in figure 8.

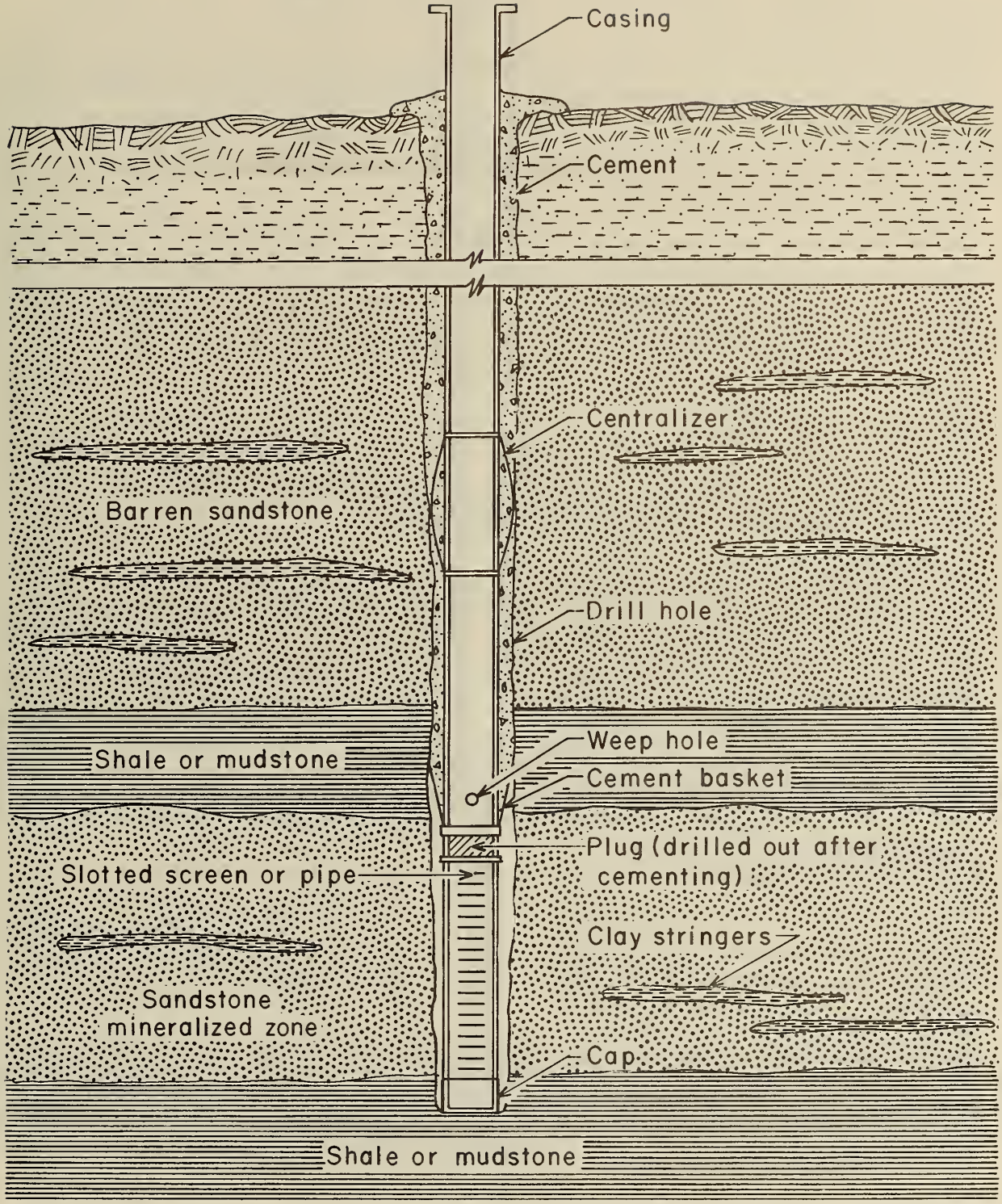

FIGURE 7. - A cross section of an injection-recovery well using a screen or slotted casing.

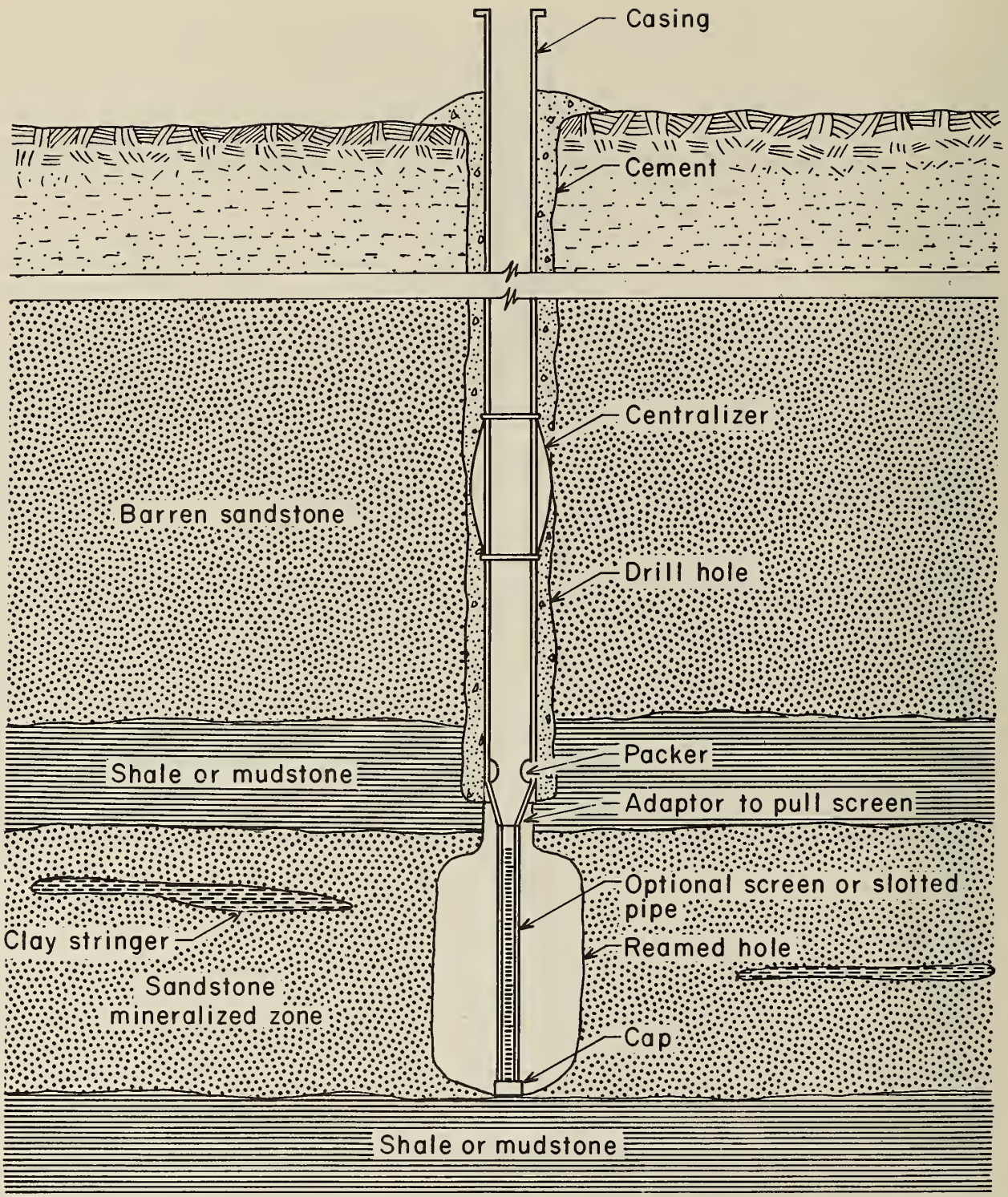

FIGURE 8. - A cross section of an injection-recovery well using a retrievable screen and underreaming techniques.

Another well construction method that has shown great potential is to use common casing and cementing techniques in conjunction with a hydraulic jet well perforator developed by the Bureau of Mines. The jet perforator has been used successfully on an experimental basis in Texas and Wyoming field sites (36).

The procedure (procedure C) used in this well construction method involves drilling a hole to the base of the mineralized zone and using cementing techniques, as previously described, to cement the casing from the hole bottom to the surface. The jet perforator is lowered down the casing opposite the ore zone. The system uses a high-pressure jet to cut small diameter holes (≃0.1-in) or slots through the PVC casing, cement, and out into the ore-bearing formation. Tests have shown that the hydraulic jet penetrates out about 1 to 1-1/2 feet into the sandstone formation.

A cross section of an in situ leaching well completed by the hydraulic jet perforator method is shown in figure 9.

The perforator completion method has several advantages over the previous well construction methods which are as follows:

1. The perforations through the casing and cement can be sized so that sand control is achieved; therefore, well screens are not needed.

2. The water jet perforator has been used to stimulate injectivity in injection wells that indicate subpar flow rates and have not responded to acidizing.

3. The water jet agitates the sands next to the drill hole, which can enhance permeability.

4. The perforations can be placed in the casing wall of a recovery well so that the leach solution flows uniformly through the mineralized zone, thus channeling at the top of the mineralized zone can be avoided.

5. This method permits the accurate placement of the perforations adjacent to the mineralized zones in the hole.

6. Experiments have shown that the jet perforator can operate in wells as small as 2 inches in diameter giving promise to a reduction in the size of the drill holes and casing required for injection wells.

7. The water jet cuts cavities into cemented sands, extending the well diameter. Two benefits are derived from this technique; the redistribution of flow tends to reduce turbulence in the vicinity of the perforations minimizing turbulent losses that may cause precipitation of carbonate, and the reduction of flow velocity tends to reduce the amount of sand carried into the well.

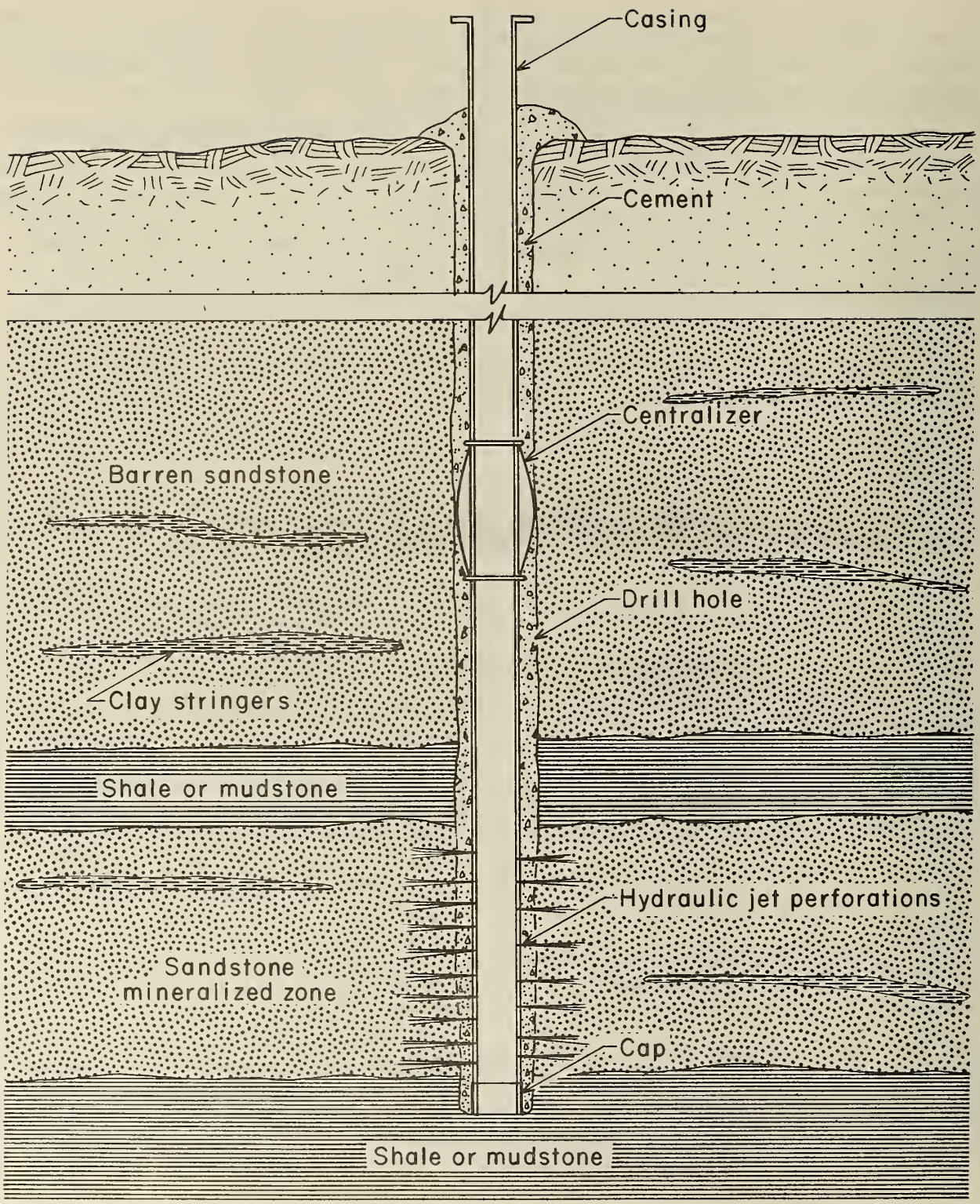

FIGURE 9. - A cross section of an injection-recovery well using the hydraulic jet perforator.

RECENT AND CURRENT URANIUM IN SITU LEACH MINING OPERATIONS

The number of new pilot-scale uranium in situ leaching operations is increasing almost monthly. Both new companies and operators that have completed pilot-scale or commercial operations are applying for new or expanded source material licenses. This activity is particularly true for Texas, Wyoming, and New Mexico. Table 1 describes the recent and current uranium in situ leaching operators, including their locations as of January 1978. In addition to the table, figures 10 and 11 show the general locations of the operators in Texas and Wyoming.

TABLE 1. - Summary of current uranium in situ leaching operations

Operator	Name, location, and description	Reference
NuBeth Joint Venture Nuclear Dynamics Inc. (operator) Bethlehem Steel Corp.	Sundance Project, E 1/2, Sec. 18, T 53 N, R 67 W, Crook County, Wyo. Research and development scale initial tests will be conducted on a single five-spot pattern with plans to expand into a pilot-scale operation capable of throughput rates of 90 gpm to processing plant.	56
Minerals Exploration Co...	Red Desert site (first site), Sec. 29, T 24 N, R 93 W, Sweetwater County, Wyo. Research and development scale initial tests conducted on a single five-spot pattern, site inactive. Red Desert site (second site), Sec. 20 and 29, T 24 N, R 93 W, Sweetwater County, Wyo. Research and development scale tests conducted on two five-spot patterns; plans are to expand into a pilot-scale operation.	55
Cotter Corp. (previously URANERZ, U.S.A., Inc.)	Charlie site, Sec. 25 and 36, T 45 N, R 77 W, Johnson County, Wyo. Research and development scale tests will be conducted on a series of five-spot patterns.	51
Exxon Co., U.S.A.....	Highland site, Sec. 20 and 21, T 36 N, R 72 W and Sec. 23 and 24, T 36 N, R 73 W, Converse County, Wyo. Research and development scale tests run from 1972 to 1974. Plans are to expand into a commercial-scale operation with a throughput rate of 1,200 gpm.	52-53
Kerr-McGee Nuclear Corp....	Double Eagle site, NW 1/4, Sec. 20, T 27 N, R 79 W, Carbon County, Wyo. Research and development scale tests run on a single five-spot pattern to demonstrate feasibility of in situ mining.	54

TABLE 1. - Summary of current uranium in situ leaching operations--Continued

Operator	Name, location, and description	Reference
Thunderbird Joint Venture Cleveland-Cliffs Iron Co. (operator) Getty Oil Co. Skelly Oil Co. Thunderbird Petroleum Co. Pioneer Nuclear Co. Texas Eastern Nuclear Co.	North Rolling Pin site (first site), Sec. 14, T 43 N, R 76 W, Campbell County, Wyo. Research and development scale tests conducted on two five-spot patterns, site inactive. Collins Draw site (second site), Sec. 35, T 43 N, R 76 W, Campbell County, Wyo. Research and development scale tests conducted on several five-spot patterns; maximum throughput rates to processing plant will be 100 to 150 gpm.	50
Rocky Mountain Energy-Halliburton Joint Venture Rocky Mountain Energy Co. (operator) Halliburton Services Brown and Root, Inc.	Bear Creek site (first site), NW 1/4, Sec. 35, T 39 N, R 73 W, Converse County, Wyo. Research and development scale. Initial tests conducted on a single five-spot pattern, site inactive. Nine-Mile Lake site (second site), Sec. 27 and 34, T 35 N, R 79 W, Natrona County, Wyo. Research and development scale. Initial tests conducted on a single seven-spot pattern, with plans to expand into a pilot-scale operation capable of throughput rates of 100 gpm to processing plant.	57
Wold Nuclear Co. (operator) Cotter Corp.	Red Desert site, Sec. 1, T 24 N, R 94 W, Sweetwater County, Wyo. Pilot-scale operation; tests will be conducted on from 4 to 10 five-spot patterns, with throughput rates of 100 gpm to the processing plant.	58
Wyoming Mineral Corp.....	Irigaray site, Numerous sections, T 45, 46, 47 N, R 77, 78 W, Johnson County, Wyo. Commercial scale operation to start in 1978 with throughput rates of 1,600 gpm to processing plant.	59
Grace Nuclear Co.....	Site No. 1, NE 1/4, Sec. 23, T 16 N, R 17 W, McKinley County, N. Mex. Pilot-scale operation used four-spot patterns, site inactive. Site No. 2, NW 1/4, Sec. 13, T 12 N, R 4 W, Sandoval County, N. Mex. Pilot-scale operations used four-spot patterns, site inactive.	31

TABLE 1. - Summary of current uranium in situ leaching operations--Continued

Operator	Name, location, and description	Reference
Wyoming Mineral Corp.....	Grover site, E 1/2, Sec. 24, T 10 N, R 62 W, Weld County, Colo. Pilot-scale operation. Numerous five-spot patterns will be in operation for a throughput rate of 200 gpm to the processing plant. Plan calls for expansion to commercial scale operation.	7
Union Carbide Corp.....	Palangana Dome site, 0.5 mile west of County Road Benevidas-Rosita and 5.4 miles north of the town of Benavides, Duval County, Tex. Commercial scale operation undergoing expansion.	39
Mobil Oil Corp.....	O'Hern site, 2.8 miles southeast of Bruni, Tex., and 600 yards south of State Highway 359, Webb and Duval Counties, Tex. Commercial scale operation undergoing expansion.	40
Wyoming Mineral Corp.....	Bruni site, 7 miles north of Bruni, Tex., and 2 miles west of Farm to Market Road 2050, Webb County, Tex. Commercial size operation.	41
	Lamprecht site, 5 miles east of Ray Point, Tex., and 2,500 feet north of Farm to Market Road 1358, Live Oak County, Tex. Commercial size operation.	42
Intercontinental Energy Corp.	Pawnee site, 2.4 miles east of Pawnee, Tex., and 0.25 mile north of Farm to Market Road 798, Bee County, Tex. Commercial scale operation with a throughput rate of 200 gpm to the processing plant.	43
	Zamzow site, 5 miles east of Ray Point, Tex., and just south of Farm to Market Road 1358, Live Oak County, Tex. Commercial scale operation.	44
United States Steel Corp...	Clay West site, 10 miles southwest of George West, Tex., and just northwest of U.S. Highway 59, Live Oak County, Tex. Commercial size operation undergoing expansion.	
United States Steel Corp. (operator) Niagara-Mohawk Uranium, Inc.	Burns site, 8 miles southwest of George West, Tex., and just south of U.S. Highway 59, Live Oak County, Tex. Commercial size operation undergoing expansion.	45

NOTE.--Additional information on particular sites is given in appendix B.

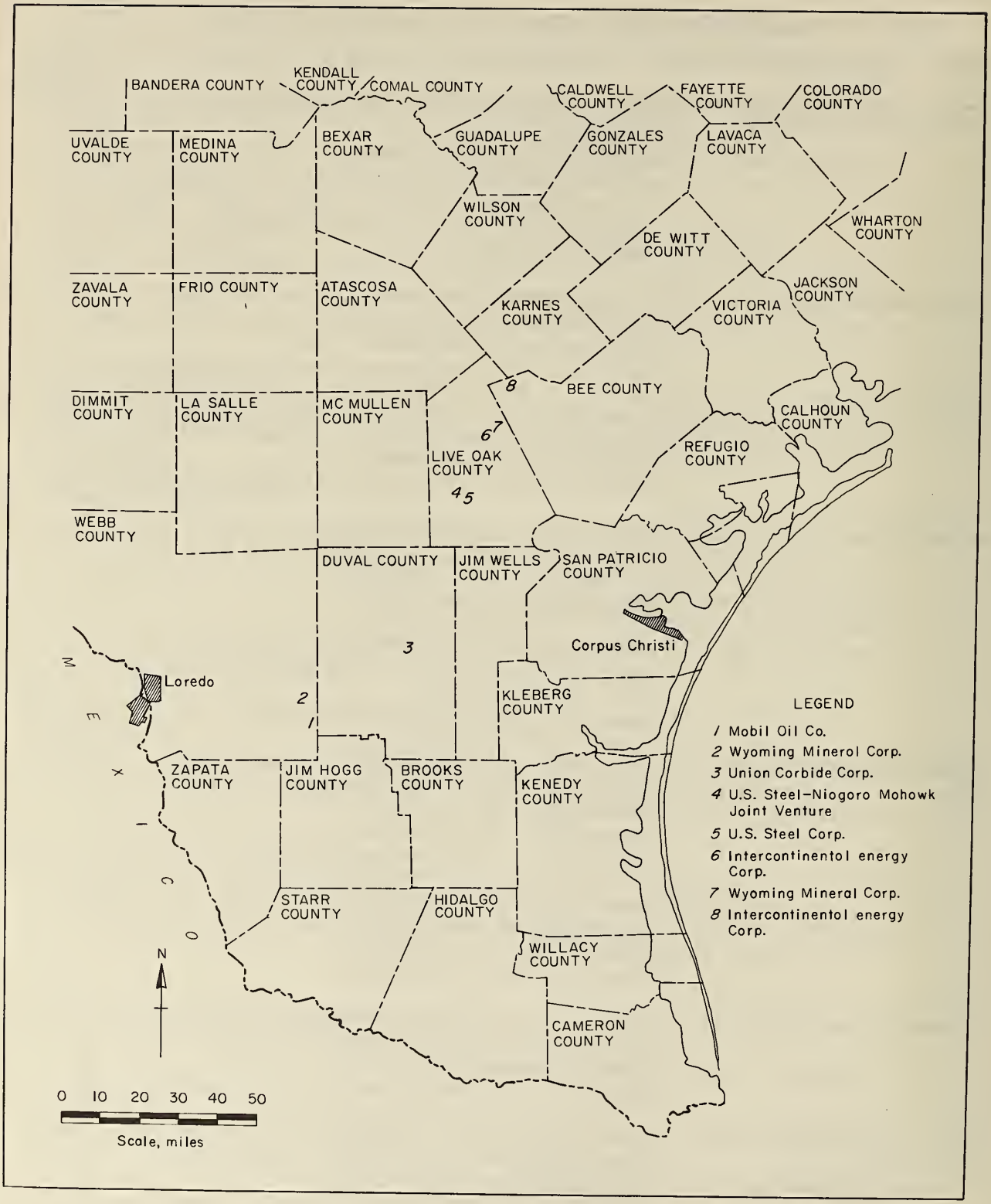

FIGURE 10: - Map of Texas showing the locations of the active uranium in situ leach mining operations.

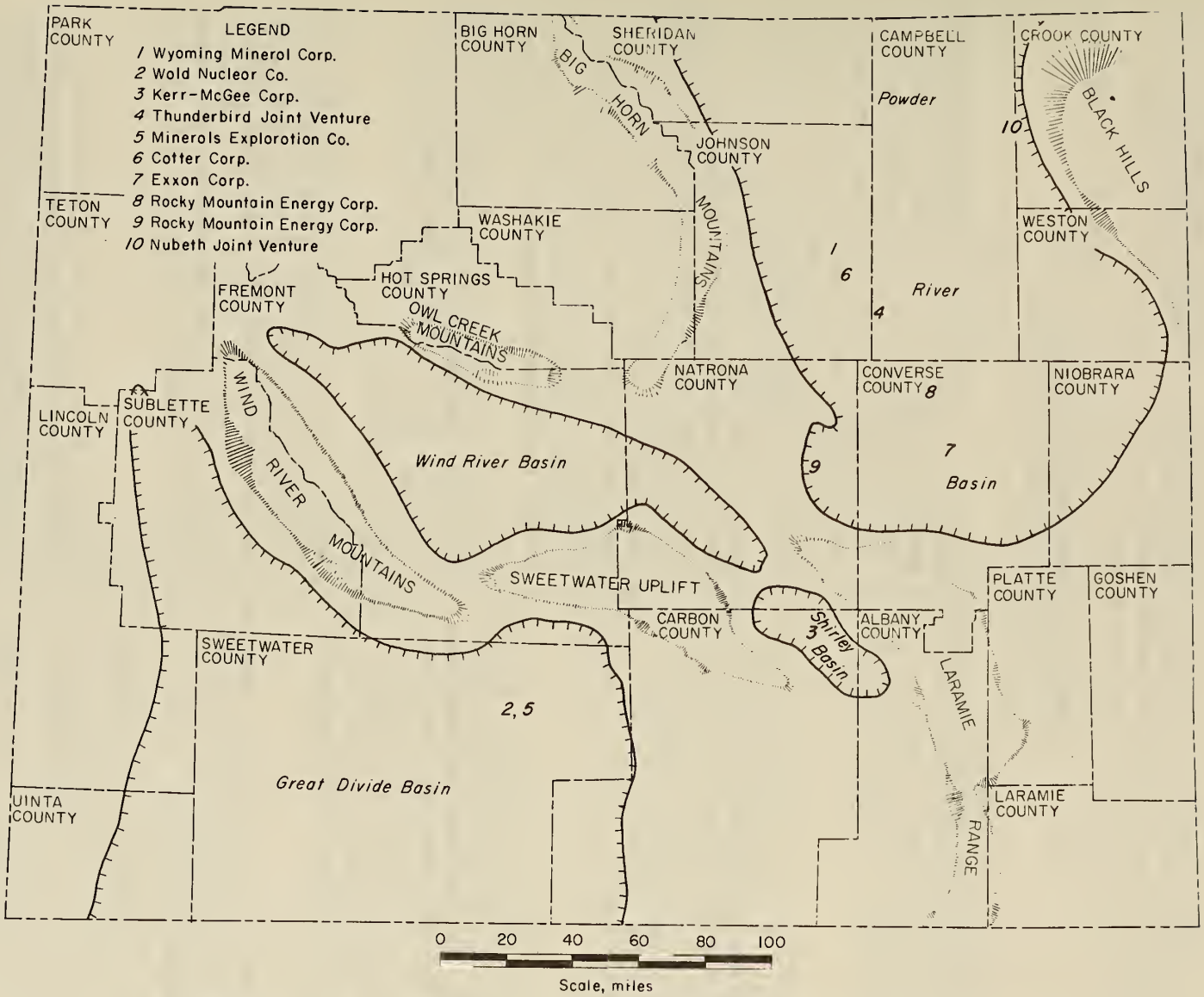

FIGURE 11. - Map of Wyoming showing the locations of the active uranium in situ leach mining operations.

CURRENT BUREAU OF MINES IN SITU URANIUM LEACH MINING RESEARCH AND OTHER GOVERNMENT AGENCY STUDIES

A summary of the current Bureau of Mines research for in situ uranium leach mining is listed in table 2. For additional and updated information the appropriate project leaders or technical project officers should be contacted. Additional information on the scope of the Bureau's in situ leach mining research can be obtained from the Twin Cities Mining Research Center (32).

TABLE 2. - Summary of recent Bureau of Mines in situ uranium leach mining research

Project or contract and project leader	Objective
Survey of the State-of-the-Art of In Situ Leach Mining William C. Larson, (612) 725-3464	Survey the state-of-the-art of in situ leach mining methods for extraction of a variety of commodities. Collect data on mining methods used, problems that have developed, new techniques being applied, costs, predict future trends, and propose future research for in situ leach mining.
Development of In Situ Leaching Technology for Uranium Daryl R. Tweeton, (612) 725-3468	Determine the best techniques to use in in situ uranium leaching. Field tests will be conducted to evaluate and develop methods of completing injection wells and to measure the changes in ground water chemistry as a function of position and time as leaching progresses. These data will be used in developing a model which will aid in optimizing the leach solution.
Computer Simulation and Modeling of Uranium In Situ Leaching Flow and Other Well and Hydrology Problems Donald I. Kurth, (612) 725-4549	Develop an expanded computer simulation model that has a multiple well analysis capability. Also develop a mass transport model as a means of computer simulation of the uranium leaching chemistry.
Water Jet Stimulation of Uranium Leaching Wells George A. Savanick, (612) 725-4543	Develop a water jet tool for enhancing permeabilities of uraniferous sands adjacent to uranium leaching wells. Also develop optimum operating parameters for this device.
Transfer of Water Jet Perforator Technology to Industry George A. Savanick, (612) 725-4543	Transfer the Bureau of Mines water jet perforator technology to industry.
Field Permeability Test Methods With Applications to Solution Mining Peter G. Chamberlain, (612) 725-4547	Provide a survey of existing permeability measuring techniques, an evaluation of them for application to leaching, and the contractor's recommendations on which technique is best suited for incorporation into routine investigations of potential leaching sites. Contract awarded in October 1976, completion date was March 1977, at a cost of $44,838.

TABLE 2. - Summary of recent Bureau of Mines in situ uranium leach mining research--Continued

Project or contract and project leader	Objective
Environmental Assessment of In Situ Mining William H. Engelmann, (612) 725-4592	Establish mitigative methods and recommend monitoring programs necessary to lessen detrimental environmental effects of both in situ leaching and hydraulic borehole mining operations. Contract awarded in July 1976, completion date is May 1978, at a cost of $113,000.
Solution Mining of Sedimentary Uranium Deposits Daryl R. Tweeton, (612) 725-3468	Provide experimental and theoretical results needed to develop a computer simulation model of the chemical reactions involved in in situ uranium leaching. Contract awarded in May 1977, completion date is May 1979, at a cost of $56,934.
Restoration of Ground Water Quality After In Situ Uranium Leaching Daryl R. Tweeton, (612) 725-3468	Evaluate existing methods of restoring the quality of ground water after in situ uranium leaching, to evaluate alternative methods, to rank the methods according to their effectiveness, and to identify technological deficiencies in the present state-of-the-art. Contract was awarded in October 1977, completion date is October 1978, at a cost of $99,825.
Develop Environmentally Attractive Leachants Daryl R. Tweeton, (612) 725-3468	Determine whether certain additives will permit potassium carbonate or sodium carbonate to be substituted for ammonium carbonate-bicarbonate without excessive loss of permeability, and determine the best compositions of these leachants for extracting uranium from several types of sandstone uranium ores Contract was awarded in February 1978, completion date is February 1980, at a cost of $98,744.
In Situ Leaching Studies on Uranium Ores Donald C. Seidel, (801) 524-5350	Development of a technique for laboratory simulation of in situ uranium leaching and the determination of the effects of leaching variables upon the permeability and uranium extraction from ores such as those found in Texas and Wyoming. Contract was awarded in March 1976, completion date is February 1979 at a cost of $351,000.

In addition to the Bureau of Mines work, several other Government agencies have let contracts or grants to obtain specific information on in situ uranium leach mining. Table 3 presents information on these additional studies sponsored by Government agencies.

TABLE 3. - Summary of other agencies current in situ uranium leach mining studies

Contract or grant, project leader, and agency	Objective
Selective Assessment of In Situ Leach Mining of Uranium Glenn A. Terry, (301) 427-4211 U.S. Nuclear Regulatory Commission Operations and Planning Branch Division of Fuel Cycle and Material Safety Washington, D.C. 20555	Provide information for Nuclear Regulatory Commission (NRC) guidance in reviewing license application for in situ leach mining of uranium. Contract was awarded in September 1977, completion date is July 1978, at a cost of $112,570.
Predicting Response of a Natural System to Uranium Extraction, Oakville Aquifer, Texas S. Jack Hubbard, (513) 684-4417 U.S. Environmental Protection Agency Industrial Environmental Research Laboratory Extraction Technology Branch 5555 Ridge Ave. Cincinnati, Ohio 45268	Determine and document for one uranium-bearing aquifer system the interrelationships between aquifer geometry, hydrology, hydrochemistry, mineralogy, and uranium mineralization, and to determine how this natural system will respond to local chemical or physical stresses induced by uranium open pit mining and leaching. A model will be developed to determine the effect of extraction on ground water quality. Grant was awarded in August 1977, completion date is August 1979, at a cost to the Environmental Protection Agency (EPA) of $230,064.
Trace and Potentially Toxic Elements Associated With Uranium Deposits in South Texas S. Jack Hubbard, (513) 684-4417 U.S. Environmental Protection Agency Industrial Environmental Research Laboratory Extraction Technology Branch 5555 Ridge Ave. Cincinnati, Ohio 45268	Ascertain whether or not there is a significant problem with toxic elements (molybdenum, arsenic, and selenium) in and around the uranium mining areas of south Texas. If found to exist, a determination of the source of the elements will be made. In addition, it will be determined whether there is significant uptake of toxic elements by vegetation. Grant was awarded in April 1977, completion date is April 1978, at a cost to the EPA of $60,000.

STATE AND FEDERAL PERMITTING AGENCIES FOR URANIUM IN SITU LEACH MINING

A listing is provided (tables 4 and 5) for those potential operators who may not be familiar with the contacts for obtaining the various permits needed to conduct in situ uranium leach mining. There are many State and Federal agencies responsible for issuing licenses for uranium leach mining; for example, discharging of liquid and solid wastes, the possession and handling of source materials, mining permits, and water well permits.

TABLE 4. - Summary of State permitting agencies for uranium in situ leach mining

Agency	Type of permit	Remarks
Colorado Department of Health Division of Radiation and Hazardous Waste Control 4210 East 11th Ave. Denver, Colo. 80220 (303) 388-6111	Source Material License	-
Colorado Department of Health Division of Water Quality Control 4210 East 11th Ave. Denver, Colo. 80220 (303) 388-6111	Subsurface Discharge Permit.	-
Department of Health and Environmental Sciences Water Quality Bureau Environmental Sciences Division Capital Station Helena, Mont. 59601 (406) 449-2406	Discharge Permit	Source Material License obtained through the NRC.
Department of Health and Environment Environmental Improvement Division Radiation Protection Bureau P.O. Box 2348 Santa Fe, N. Mex. 87503 (505) 827-5271	Radioactive Material License	- -
Do.....	Discharge Plan Approval	-
South Dakota Department of Environmental Protection Office of Water Quality Foss Building Pierre, S. Dak. 57501 (605) 224-3351	Nondischarge Permit NPDES Permit	National Pollutant Discharge Elimination System (NPDES) Permit obtained through EPA. Source Material License obtained through the NRC.
Texas Department of Water Resources P.O. Box 13087 Capital Station Austin, Tex. 78711	Nondischarge Permit	-
Texas Department of Health Radiation Control Branch 1100 West 49th St. Austin, Tex. 78756 (512) 458-7341	Radioactive Material License.	-
Department of Environmental Quality Land Quality Division Hathaway Building Cheyenne, Wyo. 82002 (307) 777-7756	Mining Permit	Source Material License obtained through the NRC.
Do.....	Discharge Permit	-
Office of the State Engineer Ground Water Section/Surface Water Section Barrett Building Cheyenne, Wyo. 82002 (307) 777-7354	Ground Water Permit Reservoir Permit	Ground Water Permit applied to the injection-recovery-monitor well system.

TABLE 5. - Summary of Federal permitting agencies for uranium in situ leach mining

Agency	Type of permit	Remarks
U.S. Nuclear Regulatory Commission Fuel Processing and Fabrication Branch Division of Fuel Cycle and Material Safety Washington, D.C. 20555 (202) 427-4103	Source Material License.	-
U.S. Environmental Protection Agency, Region VII Enforcement Division 1860 Lincoln St., Suite 900 Denver, Colo. 80203 (303) 837-3868	Surface Discharge Permit.	Region VII is defined by the following States: Colorado, Wyoming, Montana, Utah, North Dakota, and South Dakota.
U.S. Environmental Protection Agency, Region VI Enforcement Division 1st International Building 1201 Elm Street Dallas, Tex. 75270 (214) 749-1983	.....do.....	Region VI is defined by the following States: Texas and New Mexico.

The list is by no means exhaustive regarding all the permits necessary to conduct a uranium leach mining project. It is intended to serve as a "first contact" for the potential operator who is interested in initiating contacts to obtain information and guidance on permit requirements.

SUMMARY

The purpose of this report has been to give an overview of uranium in situ leach mining in the United States. Detailed technical information has been omitted so that the layperson can understand the basic principles of in situ leaching. For additional information and for a more indepth study, a list of in situ leaching publications (appendix A) is provided.

The engineering data table (appendix B) attempts to consolidate basic data from most of the current uranium in situ leaching operators. As in situ leaching techniques become more standardized, plans are to tabulate additional data for the various operators. In this way comparisons of the operations can be made to increase the available data base. Finally, the public should contact the State and Federal agencies that are discussed in this report to keep abreast of Government-sponsored research.

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8. Crawford, E. Developers Eye Texas Potential for In Situ Uranium Leaching. Eng. and Min. J., v. 176, No. 7, July 1975, pp. 81-82.

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11. Engineering and Mining Journal. New Method Suggested for Leaching Uranium Ore In-Place. V. 168, No. 5, May 1967, pp. 106-107; discussion of U.S. Patent 3,309,140, Leaching of Uranium Ore In Situ, by J. Gardner and M. I. Ritchie.

12. _____. Solution Mining Opening New Reserves. V. 175, No. 7, July 1974, pp. 62-71.

13. _____. Texas-Uranium Production by In Situ Leaching. V. 176, No. 6, June 1975, p. 304.

14. Fitch, J. L., and B. G. Hurd (assigned to Mobil Oil Corp., Dallas, Tex.). In Situ Leaching Method. U.S. Pat. 3,278,232, Oct. 11, 1966, 5 pp.

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APPENDIX B.--URANIUM IN SITU LEACHING ENGINEERING DATA

Cleveland-Cliffs Iron Co., North Rolling Pin Site, Campbell County, Wyo.

Type of operation	Pilot-scale, research and development
Source material:	
Host rock	Arkosic sandstone
Permeability, md	NA
Porosity, pct	30
Density, tons/yd^3	1.562
Ground water flow, direction	North
Surface elevation, feet above sea level	≈5,000
Geologic name	Wasatch Formation.
Geologic age	Tertiary
Ore characteristics:	
Uranium minerals	Uraninite, coffinite
Average grade, pct	0.08
Average depth, ft	125
Average thickness, ft	23
Well field characteristics:	
Total number of wells	8
Injection	3
Recovery	1
Monitor	4
Type of well pattern	Four-spot
Well spacing	25 ft between injection and recovery well
Injection well casing diameter (ID), in	4
Production well casing diameter (ID), in	4
Average depth of injection-recovery wells, ft	140-150
Type of casing	PVC, Sch. 40
Type of screens	PVC, slotted, 3 in long, 3 in apart on opposite side of casing
Leaching statistics:	
Type of leach solution	Ammonium carbonate-bicarbonate
Average concentration, g/liter	1.0-5.0
Influent (injection):	
Average total flow rate, gal/min	6
Average flow rate per well, gal/min	2
pH	NA
Effluent (production):	
Average total flow rate, gal/min	7
Average flow rate per well, gal/min	7
pH	7.3
Average uranium content, ppm	50-150
Type of oxidizer	Hydrogen peroxide
Average concentration, g/liter	0.5-1.0
Uranium concentration operation:	
Type of system	Liquid ion exchange
Rated capacity, gal/min	25
Final product	Granular yellowcake
Average uranium production, lb/day	NA
Type of waste disposal	Post-test reclamation
Average labor requirements onsite:	
Supervisory, number	0.5
General labor, do	2
Miscellaneous	Total production did not exceed 500 lb

NA--Not available.

Exxon Co., U.S.A., Highland Property, Converse County, Wyo.

Type of operation		Pilot-scale, research and development
Source material:		
Host rock		Sandstone
Permeability	md	1,088
Porosity	pct	29
Density	tons/yd^3	1.5
Ground water flow, direction		Southeast
Surface elevation, feet above sea level		≈5,300
Geologic name		Fort Union Formation
Geologic age		Paleocene
Ore characteristics:		
Uranium minerals		NA
Average grade	pct	NA
Average depth	ft	310-340
Average thickness	ft	23
Well field characteristics:		
Total number of wells		13
Injection		1
Recovery		6
Monitor		6
Type of well pattern		Seven-spot hexagonal
Well spacing		Production 90 ft from injection
Injection well casing diameter (ID)	in	5
Production well casing diameter (ID)	in	7
Average depth of injection-recovery wells	ft	330
Type of casing		Steel
Type of screens		NA
Leaching statistics:		
Type of leach solution		Sodium carbonate-bicarbonate
Average concentration	g/liter	NA
Influent (injection):		
Average total flow rate	gal/min	15
Average flow rate per well	gal/min	15
pH		NA
Effluent (production):		
Average total flow rate	gal/min	15
Average flow rate per well	gal/min	2.5
pH		NA
Average uranium content	ppm	NA
Type of oxidizer		Oxygen
Average concentration	g/liter	NA
Uranium concentration operation:		
Type of system		Solid resin ion exchange
Rated capacity	gal/min	15
Final product		Yellowcake slurry
Average uranium production	lb/day	NA
Type of waste disposal		Evaporation
Average labor requirements onsite:		
Supervisory	number	1
General labor	do	2-4
Miscellaneous		-

NA--Not available.

Intercontinental Energy Corp., Pawnee Deposit, Bee County, Tex.

Type of operation	Commercial-scale
Source material:	
Host rock	Tuffaceous sandstone
Permeability, md	5,000-10,000
Porosity, pct	30
Density, tons/yd^3	1.54
Ground water flow, direction	NA
Surface elevation, feet above sea level	750
Geologic name	Oakville sandstone
Geologic age	Miocene
Ore characteristics:	
Uranium minerals	Uraninite
Average grade, pct	0.09
Average depth, ft	240-255
Average thickness, ft	5-6
Well field characteristics:	
Total number of wells	NA
Injection	27
Recovery	11
Monitor	NA
Type of well pattern	Pod-shaped
Well spacing	40 ft between injection--80 ft between injection-recovery
Injection well casing diameter (ID), in.	4
Production well casing diameter (ID), in.	4
Average depth of injection-recovery wells, ft	NA
Type of casing	PVC
Type of screens	PVC
Leaching statistics:	
Type of leach solution	Ammonium carbonate-bicarbonate
Average concentration, g/liter	NA
Influent (injection):	
Average total flow rate, gal/min	400
Average flow rate per well, gal/min	NA
pH	NA
Effluent (production):	
Average total flow rate, gal/min	400
Average flow rate per well, gal/min	NA
pH	NA
Average uranium content, ppm	75
Type of oxidizer	Hydrogen peroxide
Average concentration, g/liter	NA
Uranium concentration operation:	
Type of system	Liquid ion exchange--steam precipitation
Rated capacity, gal/min	NA
Final product	$UO_3 \cdot H_2O$
Average uranium production, lb/day	NA
Type of waste disposal	Ponds
Average labor requirements onsite:	
Supervisory, number	3
General labor, do	12
Miscellaneous	-

NA--Not available.

Kerr-McGee Nuclear Corp., Double Eagle Claims, Shirley Basin, Wyo.

Type of operation	Pilot-scale, research and development
Source material:	
Host rock	Arkosic sandstone
Permeability, md	2,000-5,000
Porosity, pct	30
Density, tons/yd^3	NA
Ground water flow, direction	East-southeast
Surface elevation, feet above sea level	≈7,000-7,100
Geologic name	Wind River Formation
Geologic age	Eocene
Ore characteristics:	
Uranium minerals	Uraninite (major), coffinite (minor)
Average grade, pct	NA
Average depth, ft	200
Average thickness, ft	10-30
Well field characteristics:	
Total number of wells	19
Injection	4
Recovery	1
Monitor	14
Type of well pattern	Five-spot square
Well spacing	100 ft injection to injection
Injection well casing diameter (ID), in	2
Production well casing diameter (ID), in	5
Average depth of injection-recovery wells, ft	245
Type of casing	PVC, Sch. 40
Type of screens	NA
Leaching statistics:	
Type of leach solution	Sodium carbonate-bicarbonate
Average concentration, g/liter	≈3.5
Influent (injection):	
Average total flow rate, gal/min	40
Average flow rate per well, gal/min	10
pH	10
Effluent (production):	
Average total flow rate, gal/min	50
Average flow rate per well, gal/min	50
pH	9-10
Average uranium content, ppm	200
Type of oxidizer	Hydrogen peroxide
Average concentration, g/liter	1.0
Uranium concentration operation:	
Type of system	Liquid ion exchange
Rated capacity, gal/min	50
Final product	Yellowcake slurry
Average uranium production, lb/day	100
Type of waste disposal	Solar evaporation ponds
Average labor requirements onsite:	
Supervisory, number	1
General labor, do	9
Miscellaneous	-

NA--Not available.

Minerals Exploration Co., 2d Test Site, Red Desert Area, Sweetwater County, Wyo.

Type of operation		Pilot-scale, research and development
Source material:		
Host rock		Arkosic sandstone
Permeability	md	NA
Porosity	pct	30
Density	tons/yd^3	1.636
Ground water flow, direction		Southwest
Surface elevation, feet above sea level		6,600
Geologic name		Battle Springs Formation
Geologic age		Tertiary
Ore characteristics:		
Uranium minerals		Uraninite, coffinite
Average grade	pct	NA
Average depth	ft	335-380
Average thickness	ft	10-50
Well field characteristics:		
Total number of wells		21
Injection		10
Recovery		2-3
Monitor		8
Type of well pattern		Five-spot (two patterns)
Well spacing		35-50 ft injection to production
Injection well casing diameter (ID)	in	6
Production well casing diameter (ID)	in	6
Average depth of injection-recovery wells	ft	360
Type of casing		PVC, Sch. 40
Type of screens		PVC
Leaching statistics:		
Type of leach solution		Ammonium carbonate-bicarbonate
Average concentration	g/liter	1.0
Influent (injection):		
Average total flow rate	gal/min	60-80
Average flow rate per well	gal/min	8-10
pH		NA
Effluent (production):		
Average total flow rate	gal/min	60-80
Average flow rate per well	gal/min	8-10
pH		NA
Average uranium content	ppm	0-100
Type of oxidizer		Oxygen
Average concentration	g/liter	0.2-0.5
Uranium concentration operation:		
Type of system		Resin ion exchange
Rated capacity	gal/min	<80
Final product		Yellowcake slurry
Average uranium production	lb/day	NA
Type of waste disposal		Solar evaporation pond
Average labor requirements onsite:		
Supervisory	number	1
General labor	do	2 per shift
Miscellaneous		-

NA--Not available.

Rocky Mountain Energy Joint Venture, 1st Test Site, Powder River Basin, Wyo.

Type of operation	Pilot-scale, research and development
Source material:	
Host rock	Arkosic sandstone
Permeability, md	1,500 (air)
Porosity, pct	28
Density, tons/yd^3	1.562
Ground water flow, direction	Northeast
Surface elevation, feet above sea level	4,990
Geologic name	Wasatch Formation
Geologic age	Tertiary
Ore characteristics:	
Uranium minerals	Uraninite, coffinite
Average grade, pct	NA
Average depth, ft	140-170
Average thickness, ft	30
Well field characteristics:	
Total number of wells	11
Injection	4
Recovery	1
Monitor	6
Type of well pattern	Five-spot square
Well spacing	Injection 30 ft from production
Injection well casing diameter (ID), in	3, PVC Sch. 40
Production well casing diameter (ID), in	8-5/8, steel
Average depth of injection-recovery wells, ft	165
Type of casing	Injection, PVC, production
Type of screens	Stainless steel
Leaching statistics:	
Type of leach solution	Dilute sulfuric acid
Average concentration, g/liter	5-12
Influent (injection):	
Average total flow rate, gal/min	12-25
Average flow rate per well, gal/min	3-6
pH	1.0-1.35
Effluent (production):	
Average total flow rate, gal/min	25
Average flow rate per well, gal/min	25
pH	1.6-1.8
Average uranium content, ppm	50-80
Type of oxidizer	Hydrogen peroxide
Average concentration, g/liter	<1
Uranium concentration operation:	
Type of system	Liquid ion exchange
Rated capacity, gal/min	50
Final product	Yellowcake slurry
Average uranium production, lb/day	7
Type of waste disposal	Evaporation pond
Average labor requirements onsite:	
Supervisory, number	1 per shift
General labor, do	2 per shift
Miscellaneous	1 chemist, 1 project manager

NA--Not available.

Rocky Mountain Energy Joint Venture, 2d Test Site, North of Casper, Wyo.

Type of operation		Pilot-scale, research and development
Source material:		
Host rock		Sandstone
Permeability	md	500
Porosity	pct	28
Density	tons/yd^3	1.56
Ground water flow, direction		Northeast
Surface elevation, feet above sea level		5,280
Geologic name		Tea Pot sandstone
Geologic age		Tertiary
Ore characteristics:		
Uranium minerals		NA
Average grade	pct	NA
Average depth	ft	500
Average thickness	ft	25
Well field characteristics:		
Total number of wells		13
Injection		6
Recovery		1
Monitor		6
Type of well pattern		Seven-spot
Well spacing	ft	50
Injection well casing diameter (ID)	in	5
Production well casing diameter (ID)	in	5
Average depth of injection-recovery wells	ft	500
Type of casing		PVC
Type of screens		PVC and stainless steel
Leaching statistics:		
Type of leach solution		Dilute sulfuric acid
Average concentration	g/liter	5
Influent (injection):		
Average total flow rate	gal/min	35-40
Average flow rate per well	gal/min	5-10
pH		1.5
Effluent (production):		
Average total flow rate	gal/min	37-42
Average flow rate per well	gal/min	37-42
pH		1.7-2.0
Average uranium content	ppm	NA
Type of oxidizer		Hydrogen peroxide
Average concentration	g/liter	<0.5
Uranium concentration operation:		
Type of system		Liquid ion exchange
Rated capacity	gal/min	100
Final product		Yellowcake
Average uranium production	lb/day	NA
Type of waste disposal		Evaporation pond
Average labor requirements onsite:		
Supervisory	number	1
General labor	do	2 per shift
Miscellaneous		1 chemist, 1 project manager, 1 secretary-clerk

NA--Not available.

Union Carbide Corp., Palangana Dome Site, Benavides, Tex.

Type of operation		Commercial-scale
Source material:		
Host rock		Sandstone
Permeability	md	0-1,500
Porosity	pct	10-30
Density	tons/yd^3	1.823
Ground water flow, direction		Southwest
Surface elevation, feet above sea level		≈420
Geologic name		Goliad Formation
Geologic age		Pliocene
Ore characteristics:		
Uranium minerals		Uraninite
Average grade	pct	NA
Average depth	ft	310
Average thickness	ft	3-5
Well field characteristics:		
Total number of wells		163-188
Injection		60
Recovery		75-100
Monitor		28
Type of well pattern		Five-spot
Well spacing	ft	40
Injection well casing diameter (ID)	in	5
Production well casing diameter (ID)	in	5
Average depth of injection-recovery wells	ft	260
Type of casing		PVC, Sch. 40
Type of screens		PVC, perforated
Leaching statistics:		
Type of leach solution		Ammonium carbonate-bicarbonate
Average concentration	g/liter	10
Influent (injection):		
Average total flow rate	gal/min	550
Average flow rate per well	gal/min	NA
pH		NA
Effluent (production):		
Average total flow rate	gal/min	>550
Average flow rate per well	gal/min	0-20
pH		9.2
Average uranium content	ppm	NA
Type of oxidizer		Hydrogen peroxide
Average concentration	g/liter	NA
Uranium concentration operation:		
Type of system		Liquid ion exchange
Rated capacity	gal/min	NA
Final product		Uranium press cake
Average uranium production	lb/day	NA
Type of waste disposal		Evaporation ponds
Average labor requirements onsite:		
Supervisory	number	15
General labor	do	70
Miscellaneous		Deep disposal well, 04/01/78

NA--Not available.

U.S. Steel Corp., Burns Lease, George West, Tex.

Type of operation		Commercial-scale
Source material:		
Host rock		Sandstone
Permeability	md	20,000
Porosity	pct	30
Density	tons/yd^3	1.5
Ground water flow, direction		Northeast
Surface elevation, feet above sea level		300
Geologic name		Oakville
Geologic age		Miocene
Ore characteristics:		
Uranium minerals		Coffinite(?)
Average grade	pct	0.15
Average depth	ft	575
Average thickness	ft	30
Well field characteristics:		
Total number of wells		255
Injection		120
Recovery		62
Monitor		73
Type of well pattern		Five-spot
Well spacing	ft	100
Injection well casing diameter (ID)	in	4
Production well casing diameter (ID)	in	6
Average depth of injection-recovery wells	ft	575
Type of casing		PVC
Type of screens		PVC
Leaching statistics:		
Type of leach solution		Ammonium carbonate-bicarbonate
Average concentration	g/liter	NA
Influent (injection):		
Average total flow rate	gal/min	4,000
Average flow rate per well	gal/min	45
pH		NA
Effluent (production):		
Average total flow rate	gal/min	4,040
Average flow rate per well	gal/min	70
pH		NA
Average uranium content	ppm	30
Type of oxidizer		Oxygen
Average concentration	g/liter	NA
Uranium concentration operation:		
Type of system		Liquid ion exchange, Mg, O precipitation
Rated capacity	lb/yr	400,000
Final product		Yellowcake
Average uranium production	lb/day	1,100
Type of waste disposal		Injection
Average labor requirements onsite:		
Supervisory	number	6
General labor	do	60
Miscellaneous		Figures above include expansion to go on-stream April 1978

NA--Not available.

U.S. Steel Corp., Clay West Operation (including Boots lease), George West, Tex.

Type of operation		Commercial-scale
Source material:		
Host rock		Sandstone
Permeability	md	2,000
Porosity	pct	30
Density	tons/yd^3	1.562
Ground water flow, direction		Northeast
Surface elevation, feet above sea level		300
Geologic name		Oakville
Geologic age		Miocene
Ore characteristics:		
Uranium minerals		Coffinite(?)
Average grade	pct	0.2
Average depth	ft	350
Average thickness	ft	10
Well field characteristics:		
Total number of wells		275 per pattern (four patterns)
Injection		125
Recovery		75
Monitor		75
Type of well pattern		Five-spot
Well spacing	ft	70
Injection well casing diameter (ID)	in	4
Production well casing diameter (ID)	in	6
Average depth of injection-recovery wells	ft	350
Type of casing		PVC
Type of screens		PVC
Leaching statistics:		
Type of leach solution		Ammonium carbonate-bicarbonate
Average concentration	g/liter	NA
Influent (injection):		
Average total flow rate	gal/min	2,500 per pattern (four patterns)
Average flow rate per well	gal/min	33
pH		NA
Effluent (production):		
Average total flow rate	gal/min	2,275
Average flow rate per well	gal/min	50
pH		NA
Average uranium content	ppm	20
Type of oxidizer		Oxygen
Average concentration	g/liter	NA
Uranium concentration operation:		
Type of system		Liquid ion exchange, ammonia precipitation
Rated capacity	lb/yr	1,000,000
Final product		Yellowcake
Average uranium production	lb/day	2,740
Type of waste disposal		Injection well
Average labor requirements onsite:		
Supervisory	number	20
General labor	do	100
Miscellaneous		Includes expansion to go on-stream February 1978

NA--Not available.

Wyoming Mineral Corp., Irigaray Site, Johnson County, Wyo.

Type of operation	Research and development to commercial-scale
Source material:	
Host rock	Arkosic sandstone
Permeability, md	200-400 horizontal 10-100 vertical
Porosity, pct	30
Density, tons/yd^3	1.562
Ground water flow, direction	≈Northwest
Surface elevation, feet above sea level	4,500
Geologic name	Wasatch Formation
Geologic age	Tertiary
Ore characteristics:	
Uranium minerals	Uraninite, coffinite
Average grade, pct	NA
Average depth, ft	250-350
Average thickness, ft	5-15
Well field characteristics:	
Total number of wells	NA
Injection, pct	50
Recovery, pct	40
Monitor, pct	10
Type of well pattern	Modified five-spot
Well spacing	25 ft from injection to production
Injection well casing diameter (ID), in.	4-6
Production well casing diameter (ID), in.	4-6
Average depth of injection-recovery wells, ft	250-350
Type of casing	PVC
Type of screens	PVC, perforated, open
Leaching statistics:	
Type of leach solution	Ammonium carbonate-bicarbonate
Average concentration, g/liter	0.5-2.0
Influent (injection):	
Average total flow rate, gal/min	NA
Average flow rate per well, gal/min	5-10
pH	7.8-8.2
Effluent (production):	
Average total flow rate, gal/min	NA
Average flow rate per well, gal/min	5-10
pH	8.0
Average uranium content, ppm	NA
Type of oxidizer	Hydrogen peroxide
Average concentration, g/liter	0.5-2.0
Uranium concentration operation:	
Type of system	Liquid ion exchange
Rated capacity, gal/min	NA
Final product	Yellowcake
Average uranium production, lb/day	NA
Type of waste disposal	Solar evaporation pond
Average labor requirements onsite:	
Supervisory, number	25
General labor, do	35
Miscellaneous	-

NA--Not available.

Wyoming Mineral Corp., Lamprecht Site, Ray Point, Tex.

Type of operation		Commercial-scale
Source material:		
Host rock		Sandstone
Permeability	md	1,000-3,000
Porosity	pct	30
Density	tons/yd^3	1.5
Ground water flow, direction		Northeast
Surface elevation, feet above sea level		1,000
Geologic name		Oakville sandstone
Geologic age		Miocene
Ore characteristics:		
Uranium minerals		Uraninite, coffinite
Average grade	pct	NA
Average depth	ft	230-275
Average thickness	ft	10
Well field characteristics:		
Total number of wells		NA
Injection	pct	45
Recovery	pct	45
Monitor	pct	10
Type of well pattern		Variable
Well spacing		Variable (35-75 ft)
Injection well casing diameter (ID)	in	4-6
Production well casing diameter (ID)	in	4-6
Average depth of injection-recovery wells	ft	230-275
Type of casing		PVC
Type of screens		PVC and perforations
Leaching statistics:		
Type of leach solution		Ammonium carbonate
Average concentration	g/liter	0.5-2.0
Influent (injection):		
Average total flow rate	gal/min	NA
Average flow rate per well	gal/min	5-50
pH		6-8
Effluent (production):		
Average total flow rate	gal/min	NA
Average flow rate per well	gal/min	5-50
pH		6-8
Average uranium content	ppm	NA
Type of oxidizer		Hydrogen peroxide
Average concentration	g/liter	0.5-2.0
Uranium concentration operation:		
Type of system		Liquid ion exchange
Rated capacity	gal/min	NA
Final product		Yellowcake
Average uranium production	lb/day	NA
Type of waste disposal		Solar evaporation ponds, disposal wells
Average labor requirements onsite:		
Supervisory	number	25
General labor	do	30
Miscellaneous		-

NA--Not available.

Wyoming Mineral Corp., Bruni Site, Bruni, Tex.

Type of operation		Commercial-scale
Source material:		
Host rock		Sandstone
Permeability	md	200-500
Porosity	pct	30
Density	tons/yd^3	NA
Ground water flow, direction		Northeast
Surface elevation, feet above sea level		800
Geologic name		Catahoula sandstone
Geologic age		Miocene
Ore characteristics:		
Uranium minerals		Uraninite, coffinite
Average grade	pct	NA
Average depth	ft	≈120-160
Average thickness	ft	≈10
Well field characteristics:		
Total number of wells		NA
Injection	pct	45
Recovery	pct	45
Monitor	pct	10
Type of well pattern		Five-spot modified
Well spacing		25-30 ft from injection to production
Injection well casing diameter (ID)	in	4-6
Production well casing diameter (ID)	in	4-6
Average depth of injection-recovery wells	ft	120-160
Type of casing		PVC
Type of screens		PVC, open, perforated
Leaching statistics:		
Type of leach solution		Ammonium carbonate-bicarbonate
Average concentration	g/liter	0.5-2.0
Influent (injection):		
Average total flow rate	gal/min	NA
Average flow rate per well	gal/min	2-10
pH		7.5-8.8
Effluent (production):		
Average total flow rate	gal/min	NA
Average flow rate per well	gal/min	2-10
pH		7.5-8.8
Average uranium content	ppm	NA
Type of oxidizer		Hydrogen peroxide
Average concentration	g/liter	0.5-2.0
Uranium concentration operation:		
Type of system		Liquid ion exchange
Rated capacity	gal/min	NA
Final product		Yellowcake
Average uranium production	lb/day	NA
Type of waste disposal		Solar evaporation pond
Average labor requirements onsite:		
Supervisory	number	25
General labor	do	30
Miscellaneous		-

NA--Not available.

APPENDIX C.--GLOSSARY OF COMMON TERMS ASSOCIATED WITH URANIUM IN SITU LEACH MINING

Barrier Well.--Term has been used synonomously with monitor well.

Deep Disposal Well.--Well used to inject liquid wastes produced by uranium in situ mining into a deep aquifer.

Deep Injection Well.--Term has been used synonomously with deep disposal well.

Deep Monitor Well.--Function is the same as a monitor well, but located in a lower stratigraphic horizon below the ore body and used to detect downward migration of lixiviant within or around the periphery of the well field.

Excursion.--The movement of lixiviant away from the well field either laterally or vertically and shown to have been detected in the monitor wells. The term usually denotes that corrective action must be taken to bring the lixiviant back to the well field.

Guard Well.--Term has been used synonomously with monitor well; however, the term has also been used synonomously with trend well.

Huff and Puff Method.--Term used to describe a leaching method whereby a volume of leach solution is injected (injection well) into the ore body, allowed to leach the surrounding ore, and the pregnant solution pumped out of the ore body through the original injection well.

Injection Well.--The term given to a well used to inject a leach solution and oxidizer, by gravity flow, or under pressure, into the ore zone.

Input Well.--Term has been used synonomously with injection well.

Leach Solution.--Term has been used synonomously with lixiviant.

Lixiviant.--The term given to the leach solution which is ready to be injected into an ore body.

Migration.--The movement of lixiviant away from the well field either laterally or vertically. Measurement is usually accomplished by the increase or change in selected parameters above previously established control limits, as evidenced in the monitor wells or trend wells.

Mine Field.--Term has been used synonomously with well field.

Monitor Well.--Surveillance wells usually located in the same ore-bearing zone as the well field, and used for indicating containment or migration of lixiviant around the periphery of the well field.

Observation Well.--Term has been used synonomously with monitor well.

Output Well.--Term has been used synonomously with production well.

Production Field.--Well or mine field(s) which are actively being used to supply uranium-bearing solution to the processing plant.

Production Well.--The term given to a well used to recover the uranium-bearing leach solution, accomplished by pumping the solution from the ore zone to the surface for processing.

Push-Pull Method.--Term used synonomously with huff and puff method.

Ray Well.--Monitor well(s) in a line parallel with the direction of ground water flow and in line with a trend well, located within the same aquifer as the ore zone.

Recovery Well.--Term has been used synonomously with production well.

Shallow Monitor Well.--Function is the same as a monitor well but located in a higher stratigraphic horizon, above the ore body and used to detect upward migration of lixiviant within or around the periphery of the well field.

Trend Well.--Surveillance well(s) located between the well field and the monitor well(s) to serve for operational purposes, as an early warning system for a potential lixiviant excursion. These wells are usually located in the same ore-bearing zone as the well field and used for indicating migration control and lixiviant detection.

Well Completion.--Term used to describe the steps taken for drilling, casing, cementing, and developing a well so that the well will function as it was intended. Often well development is an integral part of the well completion program.

Well Development.--Term used to denote those steps taken in completing an existing well which will make the well operational. These steps may include surging, jetting, backwashing, gravel packing, etc.

Well Field.--Term used to designate a group of injection-recovery wells which when operational supply the solution feed to the processing plant.

Well Field Pattern.--Term used to denote the basic injection-recovery well configuration used in the well field. Terms commonly used are five-spot or seven-spot patterns.

Well Spacing.--Term used to describe the distance between an injection well and a recovery well. However, the term has been used to denote the distance between injection wells when describing a five-spot pattern.

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